Report No. UT-19.19

U.S. HIGHWAY 89 KANAB-PAUNSAUGUNT WILDLIFE CROSSING AND EXISTING STRUCTURES RESEARCH

Prepared For:

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Research & Innovation Division

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RESEARCH

Keeping Utah Moving
Utah Department of Transportation - Research Division
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16. Abstract

The U.S. Highway 89 Kanab-Paunsaugunt Project was constructed in 2012-2013 to help reduce mule deer-vehicle collisions and provide connectivity for the Paunsaugunt Mule Deer herds and other wildlife in their north-south movements across the highway. UDOT and partners placed 12.5 miles (20.1 km) of fence to guide wildlife to four existing structures and three new wildlife crossing culverts. The study used motion sensitive remote cameras to photograph wildlife at the structures and determine the success of each structure and the changes in mule deer movement around the fenced ends. From September 2013 through June 2018, the study cameras recorded 4.56 million photographs, 102,517 mule deer total movements at the seven structures, and 78,610 mule deer Success Movements through the seven structures. The overall Success Rate at all seven structures during the entire study was 77 percent. Six of the structures had mule deer Success Rates over 90 percent by year five of the study. Annual mule deer Success Movements through all seven structures steadily increased each year of the study. Mule deer movements around fence ends generally decreased. Mule deer Success Rate increased with increasing structure height, width, and openness ratio and decreased with increasing lengths. Before-After-Control-Impact (BACI) analyses of UDOT crash data determined there was good evidence that the wildlife crossing structures and wildlife exclusion fence had an effect on the crash rate within the mitigation section. The US 89 Kanab-Paunsaugunt project is one of the most successful mule deer mitigation projects in all of North America.

17. Key Words Wildlife crossing structures, wildlife-vehicle collisions, wildlife-vehicle conflict, WVC, animal-vehicle collisions, AVC, fence, fencing, mule deer, elk, pronghorn antelope, jack rabbit, Grand-Staircase Escalante National Monument, U.S. 89, US 89, Kanab, wildlife mitigation, Paunsaugunt, Utah, UT, BACI, performance measures		18. Distribution Statement Not restricted. Available through: UDOT Research Division 4501 South 2700 West P.O. Box 148410 Salt Lake City, UT 84114-8410 www.udot.utah.gov/go/research		23. Registrant's Seal N/A
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UNIT CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

LIST OF ACRONYMS

AADT	Annual Average Daily Traffic
AZGFD	Arizona Game and Fish Department
BACI	Before-After-Control-Impact analysis of data to determine changes over time (before/after) and space for an action (or impact) on area under consideration and a nearby comparable control area with no action
BLM	U.S. Bureau of Land Management
FHWA	Federal Highway Administration
MP	Mile Post
UDOT	Utah Department of Transportation
UDWR	Utah Division of Wildlife Resources
WVC	Wildlife Vehicle Collisions

EXECUTIVE SUMMARY

The U.S. Highway 89 Kanab-Paunsaugunt Project was constructed in 2012-2013 to help reduce mule deer-vehicle collisions and provide connectivity for the Paunsaugunt Mule Deer herds and other wildlife in their north-south movements across the highway. The Utah Department of Transportation (UDOT) worked with multiple partners to place 12.5 miles (20.1 km) of wildlife exclusion fence and three new wildlife crossing structures on U.S. Highway 89 (US 89), east of Kanab, Utah in the Grand Staircase Escalante National Monument. The goals of the mitigation project were to funnel the Paunsaugunt mule deer herds in their movements north and south through the three new wildlife crossing structures and four existing structures, and thus reduce mule deer-vehicle collisions along this stretch of highway. In September of 2013 this study was initiated with the objective to monitor wildlife movements with remote cameras at the seven structures and fence ends to determine their effectiveness. The study determined effectiveness based on five performance measures: 1. An increase in mule deer Success Movements over time until there is a plateau; 2. A mule deer Success Rate through each of the new wildlife crossing structures, at minimum be comparable with past Utah studies, 77 percent (Cramer 2012, 2014); 3. A reduction over time in mule deer numbers moving around the ends of the fence; and 4. A decrease in wildlife-vehicle collision (WVC) reported crashes in the study area. The study also looked at potential relationships with mule deer Success Rates and structure dimensions, and various wildlife species' use of the structures.

Twenty-six motion sensitive professional series cameras (Reconyx PC85 and PC800) were placed to monitor wildlife movements at the seven structures and fence ends between Mile Post (MP) 36.1 on the east and MP 48.6 on the west. Unique individual animal movements recorded by cameras at each wildlife crossing structure and fence ends were categorized and tallied as: Success Movements = movements through the wildlife crossing structure or around the fence ends; Repellency movements = movements away from wildlife crossing structure or fence ends; Parallel movements = movements parallel to the wildlife crossing structure or fence ends. Success Movements + Repellency Movements + Parallel Movements = Total Movements for each wildlife crossing structure and fence end. Success Rate was calculated as Success Movements divided by Total Movements. Annual was defined as beginning with week number

38 of the calendar year and ending with week 37 of the subsequent calendar year. This was done to standardize the years of the study across six separate calendar years.

From September 23, 2013 through June 7, 2018, the study cameras recorded 4.56 million photographs, 102,517 mule deer total movements at the seven structures, and 78,610 mule deer Success Movements through the seven structures. The overall Success Rate at all seven structures during the entire study was 77 percent. Six of the structures had mule deer Success Rates over 90 percent by year five of the study. The shortest, most narrow, and longest structure, Telegraph, had low Success Rates over the years, but had a Success Rate over 70 percent in the final year of the study. Annual mule deer Success Movements through all seven structures steadily increased each year of the study from 8,274 in 2013/14 to 23,716 in 2017/18. The number of mule deer Success Movements through the seven structures changed over time and space. There were higher numbers of Success Movements through structures during spring and fall migrations, however, mule deer used the structures during most months of the year.

Mule deer movements around fence ends generally decreased during the study. Mule deer Success Rate increased with increasing structure height, width, and openness ratio and decreased with increasing lengths. Before-After-Control-Impact (BACI) analyses of UDOT crash data determined there was strong evidence that the Pre-Construction to Post-Construction change in crash rates differed between the West Control section of US 89 and Mitigation section of US 89 ($p < 0.001$, Type I-adjusted $p = 0.001$). Overall, there was good evidence that the wildlife crossing structures and wildlife exclusion fence had an effect on the crash rate within the mitigation section. The US 89 Kanab-Paunsaugunt project is one of the most successful mule deer mitigation projects in all of North America. This is based on the project meeting its performance measures: the 78,610 mule deer Success Movements through seven structures over five years, overall annual Success Rates of all structures of 77 percent over five years, Success Rates over 90 percent at six of the seven structures the final year, the use of five structures by several elk, the use of the structures by seven additional wildlife species, and decreases in WVC in the study area Post-Construction. The results will assist UDOT and other agencies in knowing that wildlife crossing culvert designs in this project worked for mule deer.

1.0 INTRODUCTION

1.1 Problem Statement

U.S. Highway 89 (US 89) east of Kanab, Utah bisects the seasonal migration of the Paunsaugunt mule deer herd. There are thousands of mule deer in the herd, which is composed of numerous individual groups that independently migrate south in the fall toward Arizona and north in the spring toward the Paunsaugunt area near Bryce Canyon National Park and Cedar Mountain in Utah. Utah Department of Transportation (UDOT) and Utah Division of Wildlife Resources (UDWR) worked together with multiple partners to create the US 89 Kanab-Paunsaugunt Project which was constructed from 2012 - 2013. It stretches from MP 36.1 in the east to MP 48.6 in the west. The project includes 12.5 miles (20.1 kilometers) of wildlife exclusion fence on both sides of the road, three new wildlife crossing structures, and four existing structures (See Appendix A for structure figures), all in the Grand Staircase Escalante National Monument. A map of the Study Area is provided in Figure 1. The goal of the mitigation project was to funnel the Paunsaugunt mule deer herd through the three new wildlife crossing structures, three existing culverts, and one existing bridge in their movements north and south, and thus reduce mule deer-vehicle collisions along this stretch of highway.

1.2 Objectives

This research was initiated with the assistance of Arizona Game and Fish Department, UDOT, and UDWR. The objective of this research was to monitor wildlife movements at the seven structures and fence ends to determine their effectiveness.

1.3 Scope

The research documented:

1. Mule deer Total Movements, Success Movements, and Success Rates for the overall seven structures, at each structure, and fence ends;
2. Changes in mule deer movements and use rates over time study-wide and at each structure and fence ends, and how use rates compare to those in previous Utah studies (Cramer 2014);
3. Potential relationships between mule deer Success Rate and structure height, width, length, and openness ratio (height x width / length);
4. Other wildlife species' Success Movements at the structures; and
5. An analysis of US 89 wildlife-vehicle collision (WVC) crash data from Mile Post (MP) 30 through MP 56.

The results assisted in adaptive management of the structures and fence, and informed future efforts to facilitate all wildlife movement under roads.

1.4 Outline of Report

This report contains the following chapters and appendices:

- Chapter 1 Introduction
- Chapter 2 Mule Deer and Others Species' Use of Structures – which includes methods, results, and discussion
- Chapter 3 Analyses of the Wildlife-Vehicle Collision Crash and Mule Deer Data to Evaluate Reduction in Wildlife-Vehicle Crashes in the Study Area – which includes methods, results, and discussion
- Chapter 4 Conclusions: Evaluation of the Effectiveness of Mitigation with Respect to Performance Measures
- Chapter 5 Recommendations and Implementation
- Appendix A Structures
- Appendix B Pictures of Wildlife Species at Structures
- Appendix C A Comparison of Crash Numbers and Carcass Numbers by Year, East Control, Mitigation, and West Control Sections

2.0 MULE DEER AND OTHER SPECIES' USE OF STRUCTURES

2.1 Overview

U.S. Highway 89 (US 89) east of Kanab, Utah bisects the seasonal migration of the Paunsaugunt mule deer herd. There are thousands of mule deer in the herd, which is composed of numerous individual groups that independently migrate south in the fall toward Arizona and north in the spring toward the Paunsaugunt area near Bryce Canyon National Park and Cedar Mountain in Utah. Utah Department of Transportation (UDOT) and Utah Division of Wildlife Resources (UDWR) worked together with multiple partners to create the US 89 Kanab-Paunsaugunt Project which was constructed from 2012 - 2013. It stretches from MP 36.1 in the east to MP 48.6 in the west. The project includes 12.5 miles (20.1 kilometers) of wildlife exclusion fence on both sides of the road, three new wildlife crossing structures, and four existing structures (See Appendix A for structure figures), all in the Grand Staircase Escalante National Monument. A map of the Study Area is provided in Figure 1. The goal of the mitigation project was to funnel the Paunsaugunt mule deer herd through the three new wildlife crossing structures, three existing culverts, and one existing bridge in their movements north and south, and thus reduce mule deer-vehicle collisions along this stretch of highway. Details of the locations and dimensions of the seven structures are provided in Table 1.

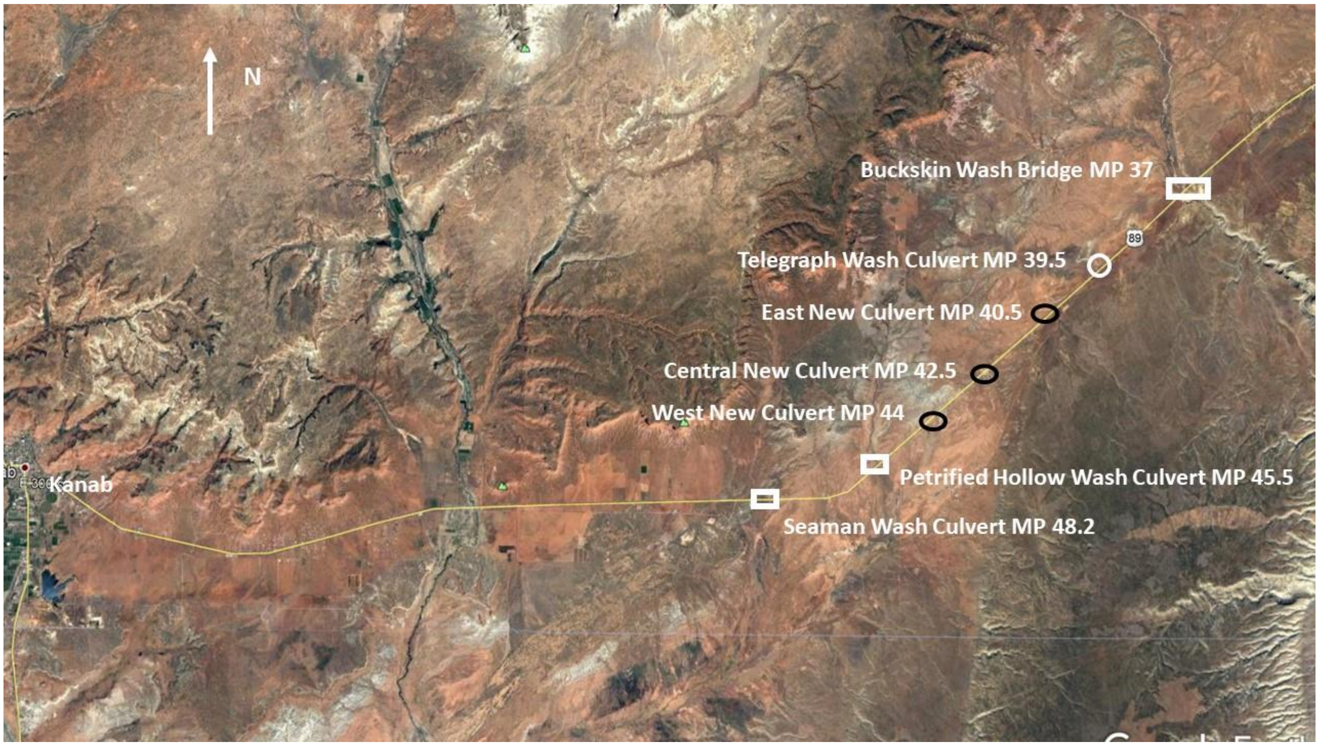

Figure 1. Map of Study Area on US 89 and Structures Monitored. New Structures Are Displayed in Black Ovals; Existing Structures Are Displayed in White Boxes and a White Circle.

Table 1. Structures Monitored in This Study, Their Mile Post (MP) Location, Height, Width, and Length in Feet.

Structure Name and Type	MP	Height in Feet	Width	Length
East Fence End	36.1			
Buckskin Existing Concrete Bridge	37	30	55	44
Telegraph Existing Corrugated Steel Culvert	39.5	7.5	6	84
East New Wildlife Crossing Corrugated Steel Culvert	40.5	8.5	15.5	52
Center New Wildlife Crossing Corrugated Steel Culvert	42.5	8.5	15.5	52
West New Wildlife Crossing Corrugated Steel Culvert	44	12	18.6	68
Petrified Existing Concrete Box Culvert	45.5	10	23	77
Seaman Existing Concrete Box Culvert	48.2	12	24	75
West Fence End	48.6			

2.2 Methods

On September 23, 2013, 28 motion sensitive Reconyx professional series cameras (PC85 and PC800) were placed at the entrances to the seven structures, fence ends, and two double cattle guards. Cameras were removed on June 7, 2018. Cameras were triggered by motion and took pictures of large and small animals, day and night. Cameras were programmed with the following Reconyx trigger-settings: high sensitivity, five pictures per trigger, rapid-fire picture interval, and no delay quiet period.

The three new structures and existing culverts were monitored with three cameras. Buckskin was monitored with four cameras through mid-September, 2017. At each structure:

- One camera was installed in a locked metal box on a metal post on the north side of each structure, approximately 30 feet (9.1 m) from the entrance, facing inside the structure.
- A second camera was mounted in a locked metal box on the south side of each structure, generally facing toward the south. Buckskin had two cameras mounted to the south end of the structure.
- A third camera was installed in a locked metal box on a steel post, on the north side of each structure 100 feet (30.5 meters) from structure entrances. These cameras faced wild areas, generally towards the north.

The cameras were mounted on the south side of structures rather than on posts to prevent the cameras from washing away during flash floods, which are common in the area and have a tendency to blow out soil and vegetation from the south side of structures. The Buckskin north camera was washed away in a flash flood in mid-September, 2017.

Cameras were checked every 4 to 8 weeks to exchange data cards and batteries.

Photographic data were analyzed in a consistent method that evaluated wildlife movements each time animals triggered the cameras. Mule deer movements, not individual animals, were tallied. Unique individual animal movements recorded by cameras at each wildlife crossing structure, fence ends, and cattle guards were categorized and tallied as follows:

- **Success Movements** = movements through the wildlife crossing structure or around the fence ends;
- **Repellency Movements** = movements away from wildlife crossing structure or fence ends;
- **Parallel Movements** = movements parallel to the wildlife crossing structure or fence ends.

Success Movements + **Repellency Movements** + **Parallel Movements = Total Movements** for each wildlife crossing structure and fence end.

Unique individual animal movements were tallied only once, even if more than one camera recorded the movement. Individual Repellency and Parallel Movements were tallied only once when the same animal moved in front of a camera for an extended period of time. Multiple Success Movements were tallied, even when the same animal made more than one success movement. When animals moved continuously in front of a camera for an extended period of time, a final movement determination was made after one hour. The following calculations were made for each wildlife crossing structure and each fence end:

- **Success Rate** = Success Movements divided by Total Movements,
- **Rate of Repellency** = Repellency Movements divided by Total Movements,
- **Parallel Rate** = Parallel Movements divided by Total Movements, and
- **Camera Operation Rate** = the average number of days cameras were in operation at the structure or fence end divided by the number of days in the monitoring period.

Simple scatter plots of overall mule deer Success Rates with heights, widths, lengths, and openness ratios were created in Excel 2016. Openness ratio was defined as height multiplied by width, divided by length, calculated in both feet and meters.

Mule deer gender and direction of origin were recorded for individual mule deer movements at the structures and fence ends from September 2013 through April 2016. Gender was recorded as male, female, or unknown. Direction of origin was recorded as north or south. January through June was considered spring and July through December was considered fall. The decision to limit this analysis was made because the nearly 4.6 million pictures generated in the study prohibited time-consumptive detailed data analyses that the individual mule deer gender and direction of origin entailed.

The cameras mounted 100 feet (30.5 m) north of the structures were positioned to capture animal movements at a distance to the structure. The objective of placing these wild area cameras was to document species of wildlife that were near the road but did not approach the entrances to the structures. These animals avoiding the road area were not accounted for with structure entrance cameras, yet their presence was important to evaluating the efficacy of the structures in providing connectivity for species present.

2.3 Results

2.3.1 Mule Deer Movements and Success Rates Study-Wide

From September 23, 2013 through June 7, 2018, the cameras recorded approximately 4.56 million photographs, 102,517 mule deer Total Movements at the wildlife crossing structures, and 78,610 mule deer Success Movements through the wildlife crossing structures. The overall Success Rate at all seven structures during the entire study was 77 percent. Appendix B presents select highlight pictures from the study.

Figure 2 presents annual mule deer Total Movements and Success Movements combined for all seven wildlife crossing structures from September 23, 2013 through June 7, 2018. Annual was defined as beginning with week number 38 of the calendar year and ending with week number 37 of the subsequent calendar year. Monitoring began in week 40 of 2013 and ended in week 23 of 2018. Total Movements decreased in the second year of the study (2014/15) and increased in the third, fourth, and fifth years of the study. Annual Success Movements increased each year of the study by an average of 30 percent.

In Figure 2, for each of the annually-paired columns, the ratio of the Success Movements (orange, right) column's value to the Total Movements (blue, left) column's value equates to the annual Success Rate. The closer the values of the paired columns, the higher the annual Success Rate. Overall annual Success Rates increased each year: 44 percent in 2013/14, 71 percent in 2014/15, 83 percent in 2015/16, 86 percent in 2016/17, and 92 percent in 2017/18.

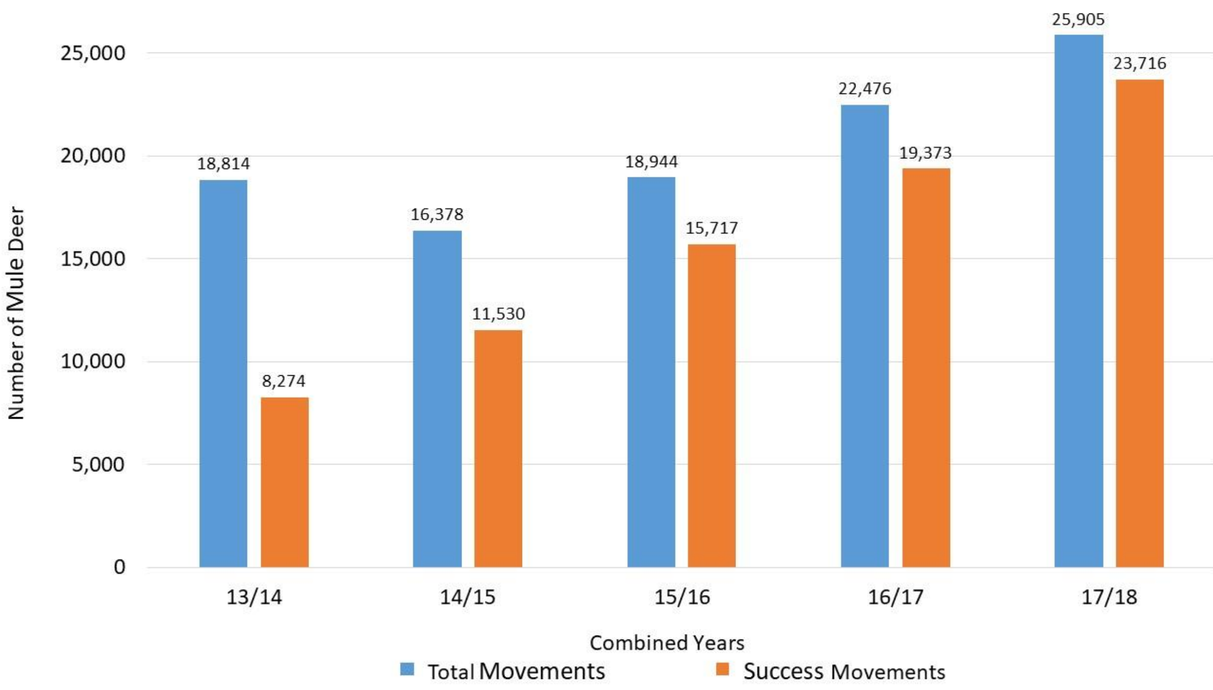

Figure 2. Annual Mule Deer Total Movements and Success Movements for All Seven Wildlife Crossing Structures on US 89 from September 23, 2013 through June 7, 2018.

Figure 3 presents monthly mule deer Total Movements and Success Movements combined for all seven structures from September 23, 2013 through June 7, 2018. Monthly-peak Total Movements and Success Movements occurred each October during fall migrations and each March and April during spring migrations. Total Movements and Success Movements were greater during spring migrations than during fall migrations, particularly in 2016, 2017, and 2018.

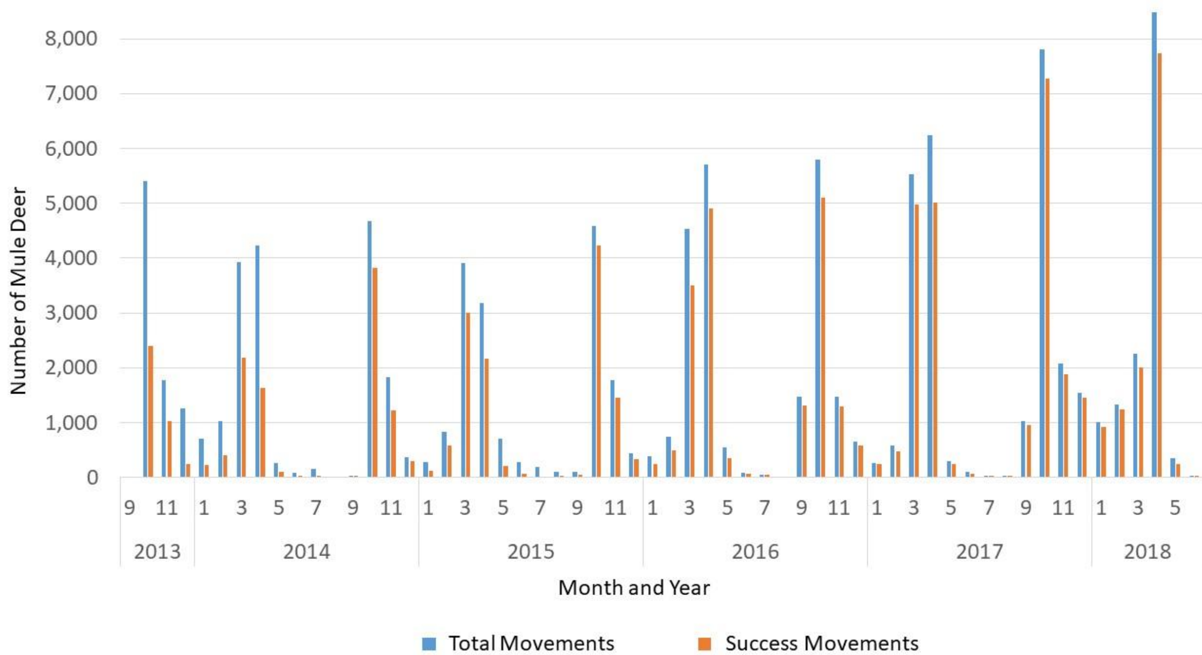

Figure 3. Monthly Mule Deer Total Movements and Success Movements Combined for All Seven Wildlife Crossing Structures from September 23, 2013 through June 7, 2018.

The number of annual Success Movements for each structure were plotted in Figure 4 to demonstrate the increased number of success movements over time, and the mule deer preferences for structures in certain locations.

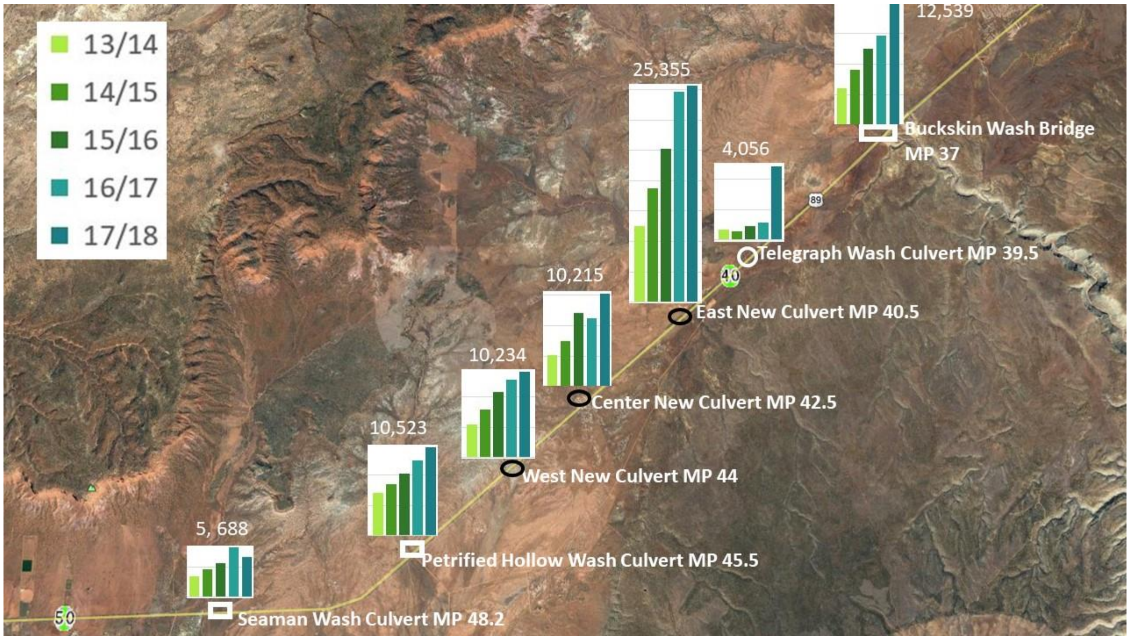

Figure 4. Number of Mule Deer Success Movements through Each Structure for each Combined Year of the Study 2013-2018.

2.3.2 Mule Deer Movements at Individual Wildlife Crossing Structures

Table 2 presents mule deer Total Movements, Success Movements, and Success Rates at the individual structures. The East New structure, MP 40.5, had more than two times the number of mule deer Success Movements (25,355) when compared to other structures. The three new wildlife crossing structures had 45,804 mule deer Success Movements, 58 percent of the Success Movements at all seven structures. Three of the existing structures had the highest mule deer Success Rates, Petrified was highest (91 percent), followed closely by Buckskin and Seaman (89 percent each). Telegraph had the lowest number of Success Movements (4,056) and the lowest Success Rate (25 percent).

Table 2. Mule Deer Movements, Success Movements, and Success Rates at Individual Structures from September 23, 2013 to June 7, 2018.

Structure Name and MP	Total Movements	Success Movements	Success Rate (%)
Buckskin, MP 37	14,028	12,539	89
Telegraph, MP 39.5	16,021	4,056	25
East New, MP 40.5	29,482	25,355	86
Center New, MP 42.5	12,963	10,215	79
West New, MP 44	12,027	10,234	85
Petrified, MP 45.5	11,600	10,523	91
Seaman, MP 48.2	6,396	5,688	89

Figure 5 displays monthly mule deer Success Movements for each of the seven structures from September 23, 2013 through June 7, 2018. Success Movements were highest at the East structure after 2013. Success Movements increased dramatically from December 2017 through February 2018 compared to other December through February periods during the study. In general, structures on the east side of the study area (East, Buckskin, Center, and Telegraph) had more Success Movements in the spring than in the fall, while structures on the west side of the study area (Petrified, West, and Seaman) had more Success Movements in the fall than in the spring.

Figure 6 plots annual mule deer Success Rates at each of the seven structures from September 23, 2013 through June 7, 2018. Each structure, with the exception of the Telegraph culvert, had a similar pattern; annual Success Rates increased, converged, and then generally stabilized. Success Rates at these six structures ranged from 46 percent to 76 percent in 2013/14, and ranged from 92 percent to 97 percent in 2017/18. Annual mule deer Success Rates at the Telegraph structure were much lower than the other six structures at the beginning of the study (six percent in 2013/14), and dramatically increased throughout the study, without stabilizing. The annual Success Rate at the Telegraph structure more than doubled from 31 percent in 2016/17 to 73 percent in 2017/18.

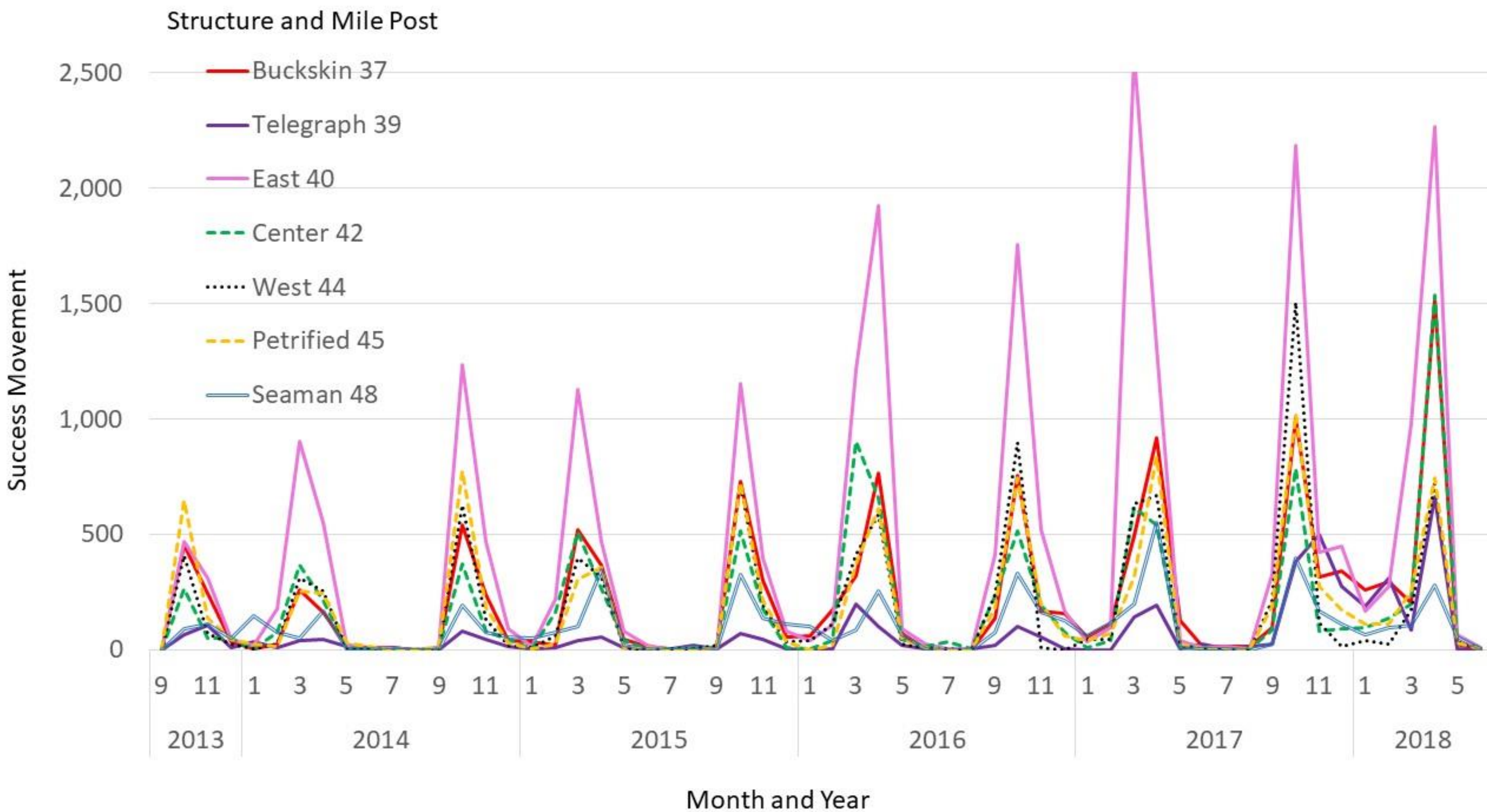

Figure 5. Superimposed Monthly Mule Deer Success Movements at Each of the Seven Structures on US 89 from September 23, 2013 through June 7, 2018.

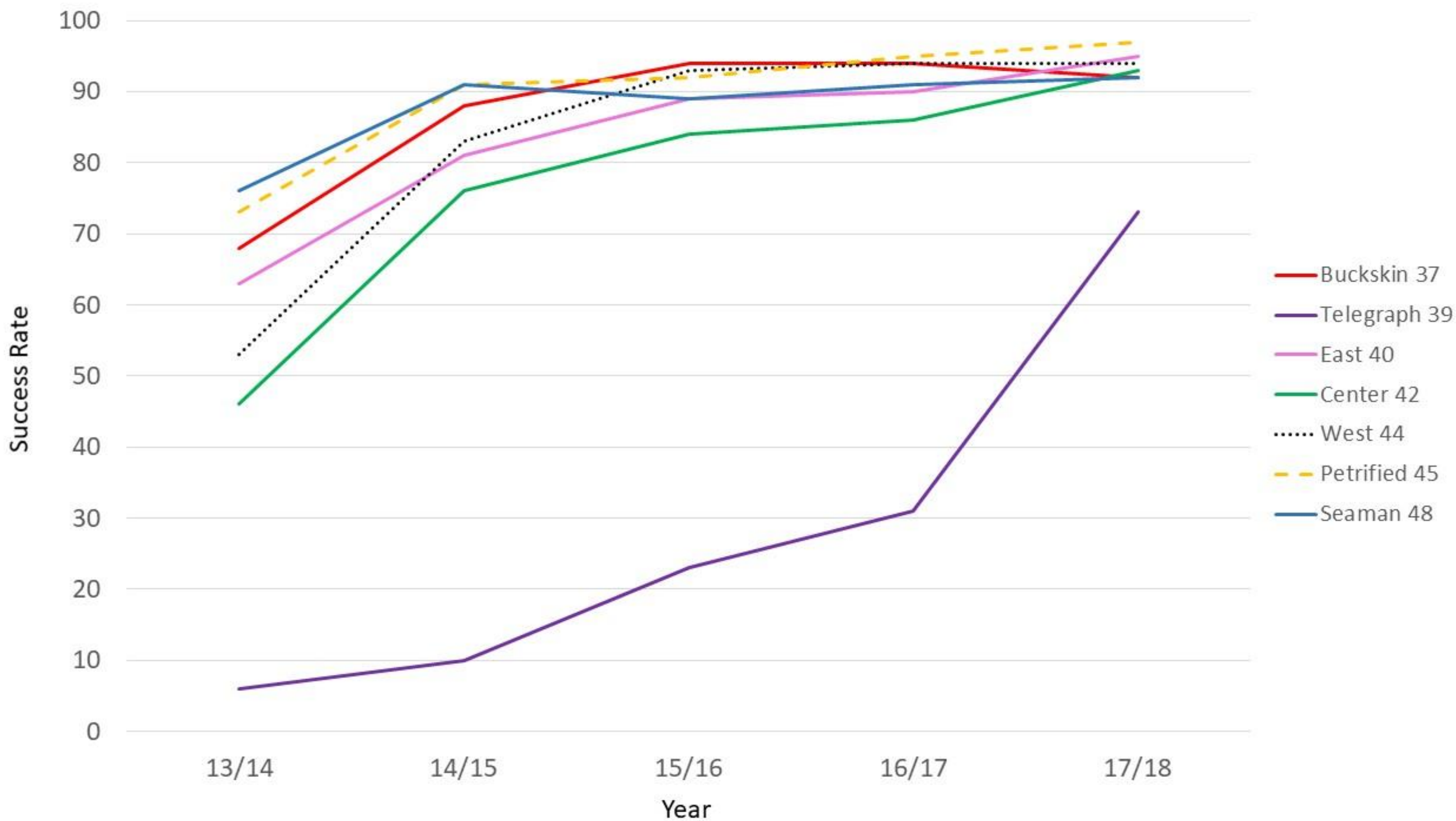

Figure 6. Annual Mule Deer Success Rates at Each Structure, 2013/2014 through 2017/2018.

2.3.2.1 Buckskin

Figure 7 presents annual mule deer Total Movements and Success Movements at the Buckskin structure from September 23, 2013 through June 7, 2018. Total Movements and Success Movements steadily increased each year. Figure 8 presents monthly mule deer Total Movements and Success Movements at the Buckskin structure from September 23, 2013 through June 7, 2018. Monthly movements generally increased during the study and peaked during fall and spring migrations. Monthly Total Movements and Success Movements increased dramatically from December 2017 through February 2018 compared to other December through February periods during the study. Monthly movements were higher during spring migrations than during fall migrations, with the exception of 2013/14. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rates and monthly Success Rates generally increased during the study. The annual Success Rate increased from 68 percent in 2013/14 to 94 percent in 2015/16 and 2016/17, then declined slightly to 92 percent in 2017/18. Camera operation rates were 89 percent in 2018, 98 percent in 2017, and 88 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

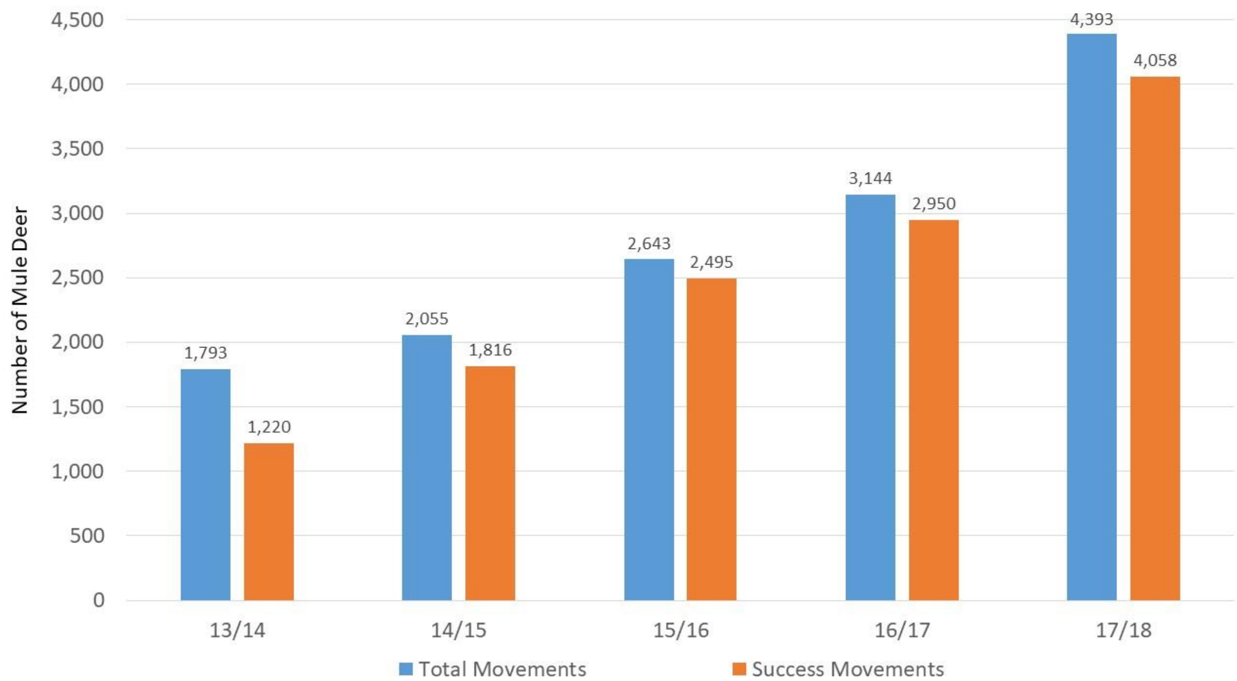

Figure 7. Annual Mule Deer Total Movements and Success Movements at the Buckskin Structure from September 23, 2013 through June 7, 2018.

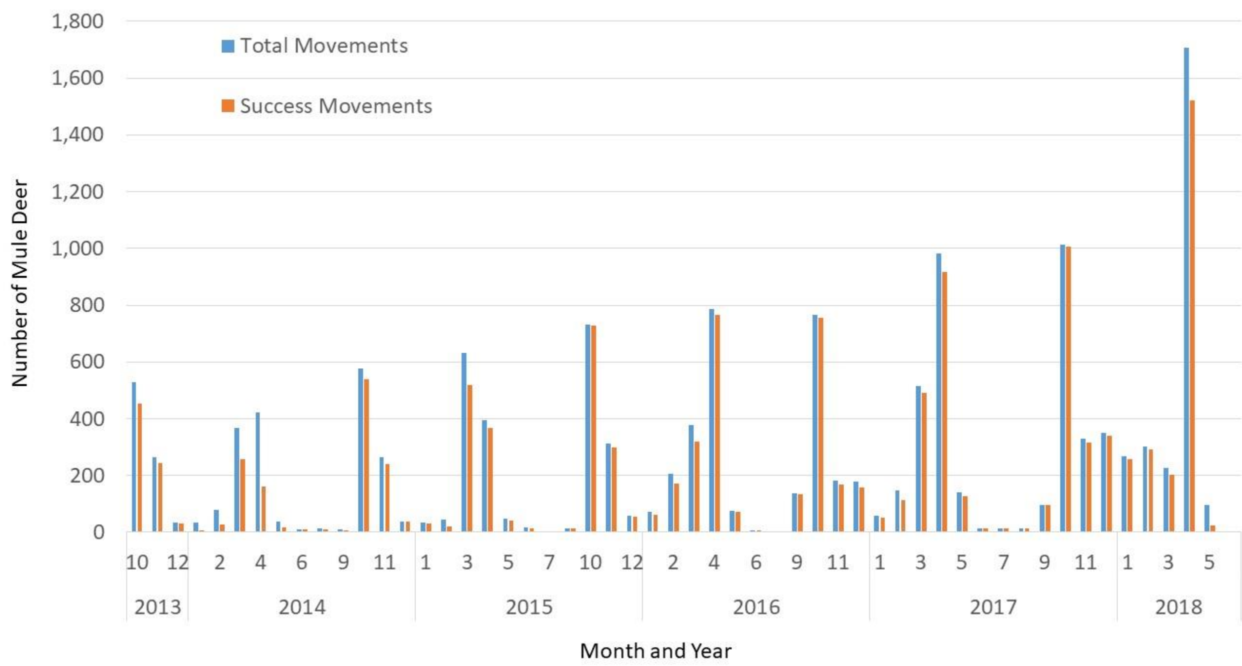

Figure 8. Monthly Mule Deer Total Movements and Success Movements at the Buckskin Structure from September 23, 2013 through June 7, 2018.

2.3.2.2 Telegraph

Figure 9 presents annual mule deer Total Movements and Success Movements at the Telegraph structure from September 23, 2013 through June 7, 2018. Total Movements decreased 51 percent from 2013/14 to 2014/15, 29 percent from 2014/15 to 2015/16, and 11 percent from 2015/16 to 2016/17. Success Movements decreased 12 percent in 2014/15, increased 57 percent in 2015/16 and 24 percent in 2016/17, and dramatically increased 332 percent in 2017/18. Figure 10 presents monthly mule deer Total Movements and Success Movements at the Telegraph structure from September 23, 2013 through June 7, 2018. Monthly movements peaked during fall and spring migrations, and increased dramatically in 2017/18. Monthly movements were generally higher during spring migrations than during fall migrations. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rates and monthly Success Rates generally increased during the study. The annual Success Rate increased from six percent in 2013/14 to 73 percent in 2017/18. Camera operation rates were 89 percent in 2018, 94 percent in 2017, and 92 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

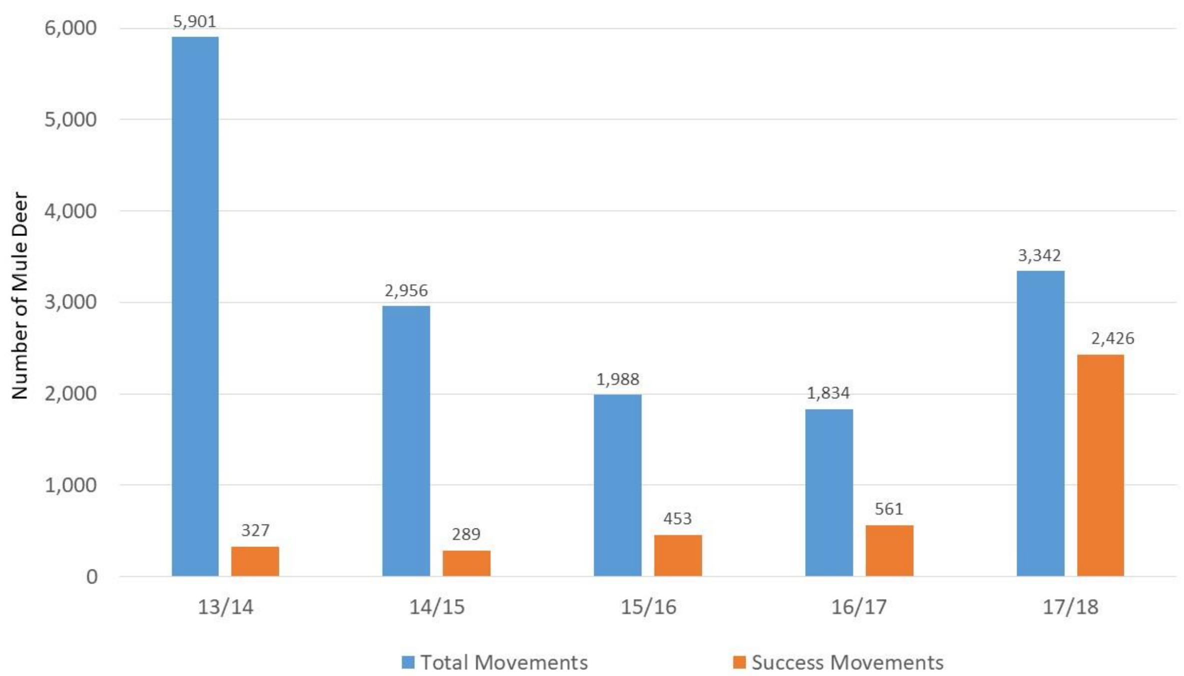

Figure 9. Annual Mule Deer Total Movements and Success Movements at the Telegraph Structure from September 23, 2013 through June 7, 2018.

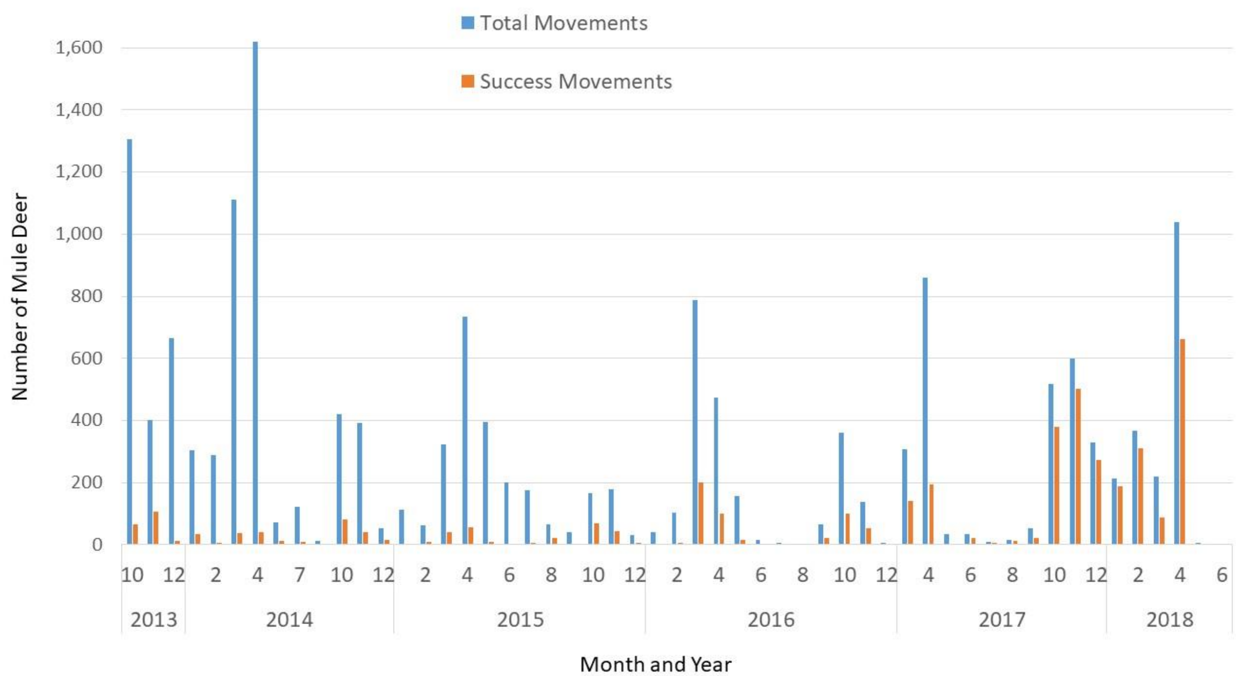

Figure 10. Monthly Mule Deer Total Movements and Success Movements at the Telegraph Structure from September 23, 2013 through June 7, 2018.

2.3.2.3 East New

Figure 11 presents annual mule deer Total Movements and Success Movements at the East New structure from September 23, 2013 through June 7, 2018. This structure had the greatest number of annual Success Movements for the duration of the study compared to the other six structures. Total Movements and Success Movements steadily increased each year through 2016/17. In 2017/18, Total Movements decreased slightly and Success Movements increased slightly compared to 2016/17. Figure 12 presents monthly mule deer Total Movements and Success Movements at the East New structure from September 23, 2013 through June 7, 2018. Monthly movements generally increased during the study, with the exception of 2017/18, and peaked during fall and spring migrations. Movements were higher during spring migrations than during fall migrations, with the exception of 2014/15. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rates and monthly Success Rates generally increased during the study. The annual Success Rate increased from 63 percent in 2013/14 to 95 percent in 2017/18. Camera operation rates were 88 percent in 2018, 96 percent in 2017, and 80 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

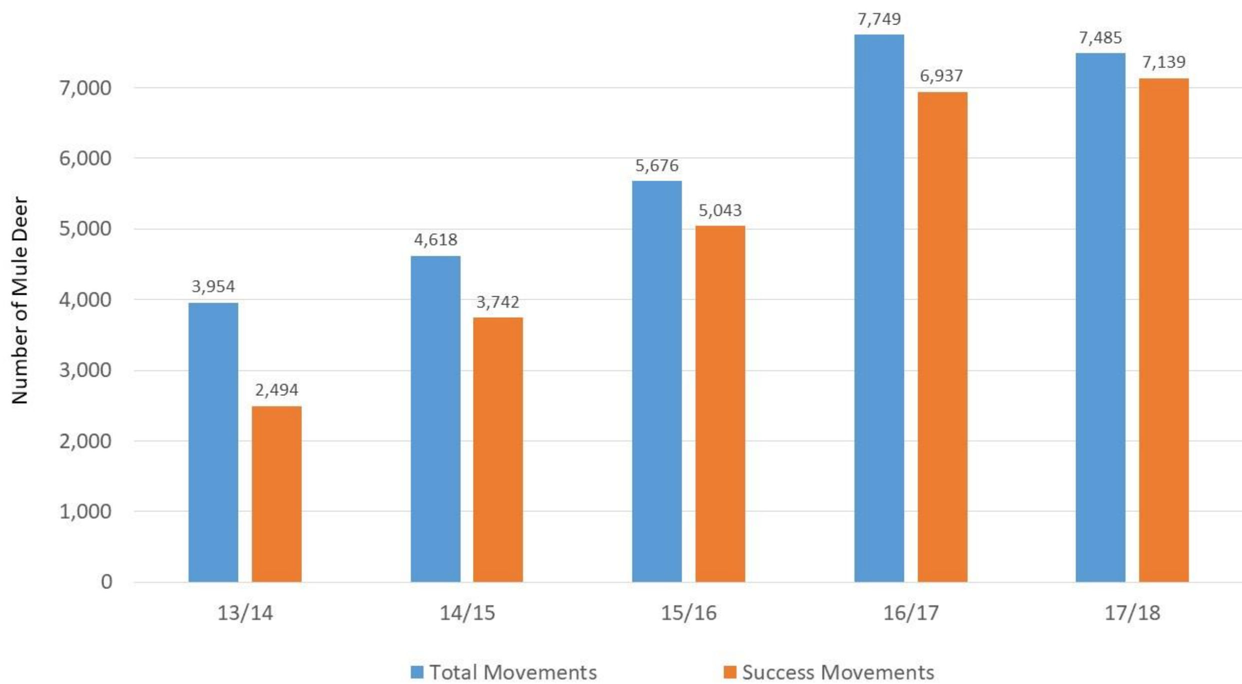

Figure 11. Annual Mule Deer Total Movements and Success Movements at the East New Structure from September 23, 2013 through June 7, 2018.

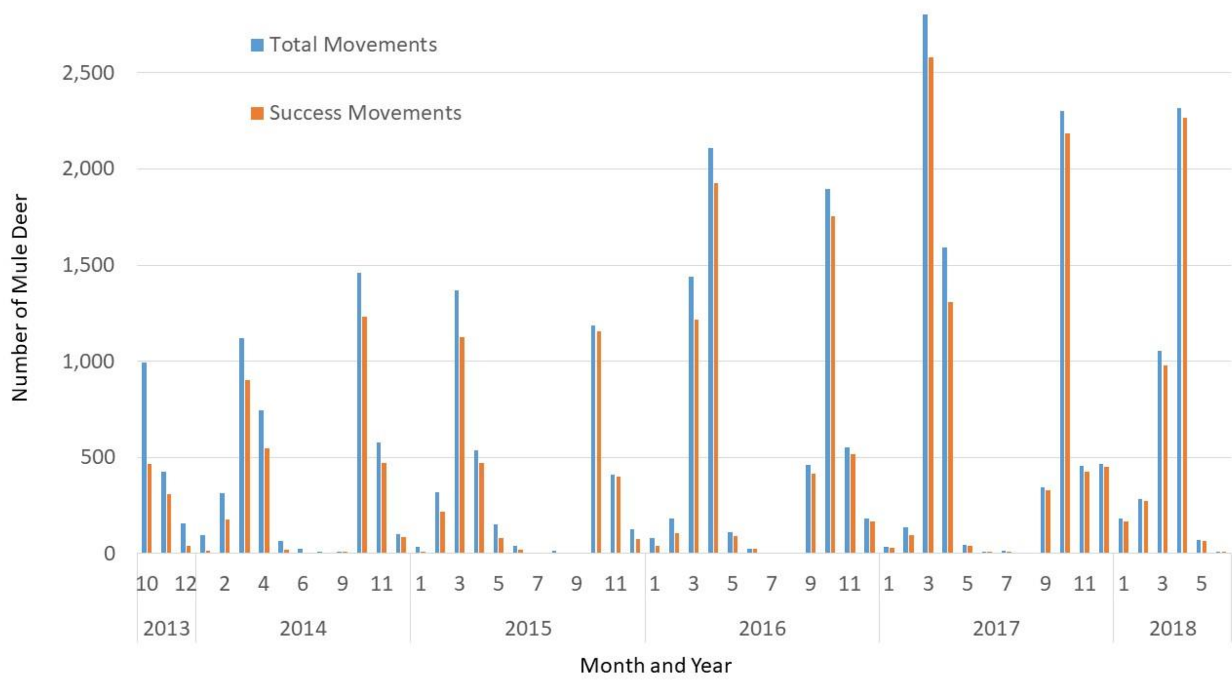

Figure 12. Monthly Mule Deer Total Movements and Success Movements at the East New Structure from September 23, 2013 through June 7, 2018.

2.3.2.4 Center New

Figure 13 presents annual mule deer Total Movements and Success Movements at the Center New structure from September 23, 2013 through June 7, 2018. Total Movements generally increased during the study with slight decreases in 2014/15 and 2016/17. Success Movements generally increased during the study with a slight decrease in 2016/17. Figure 14 presents monthly mule deer Total Movements and Success Movements at the Center New structure from September 23, 2013 through June 7, 2018. Monthly movements peaked significantly during the 2018 spring migration. Monthly movements were higher during spring migrations than during fall migrations. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rates and monthly Success Rates generally increased during the study. The annual Success Rate increased from 46 percent in 2013/14 to 93 percent in 2017/18. Camera operation rates were 96 percent in 2018, 98 percent in 2017, and 99 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

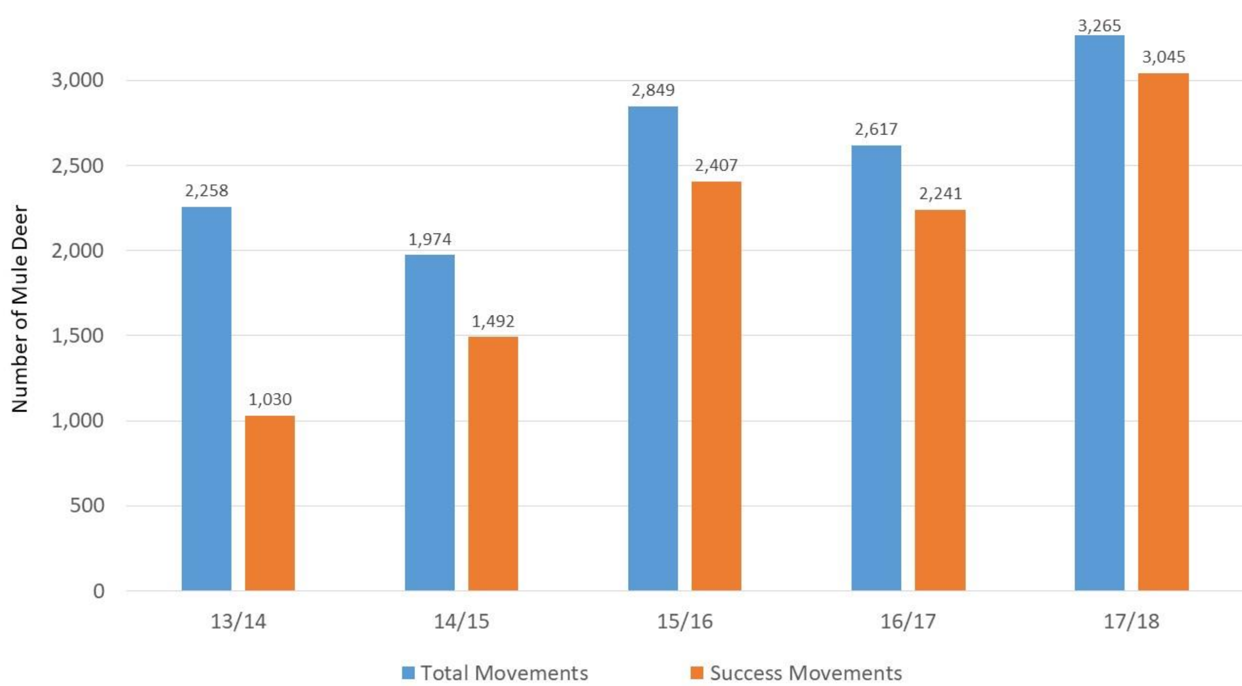

Figure 13. Annual Mule Deer Total Movements and Success Movements at the Center New Structure from September 23, 2013 through June 7, 2018.

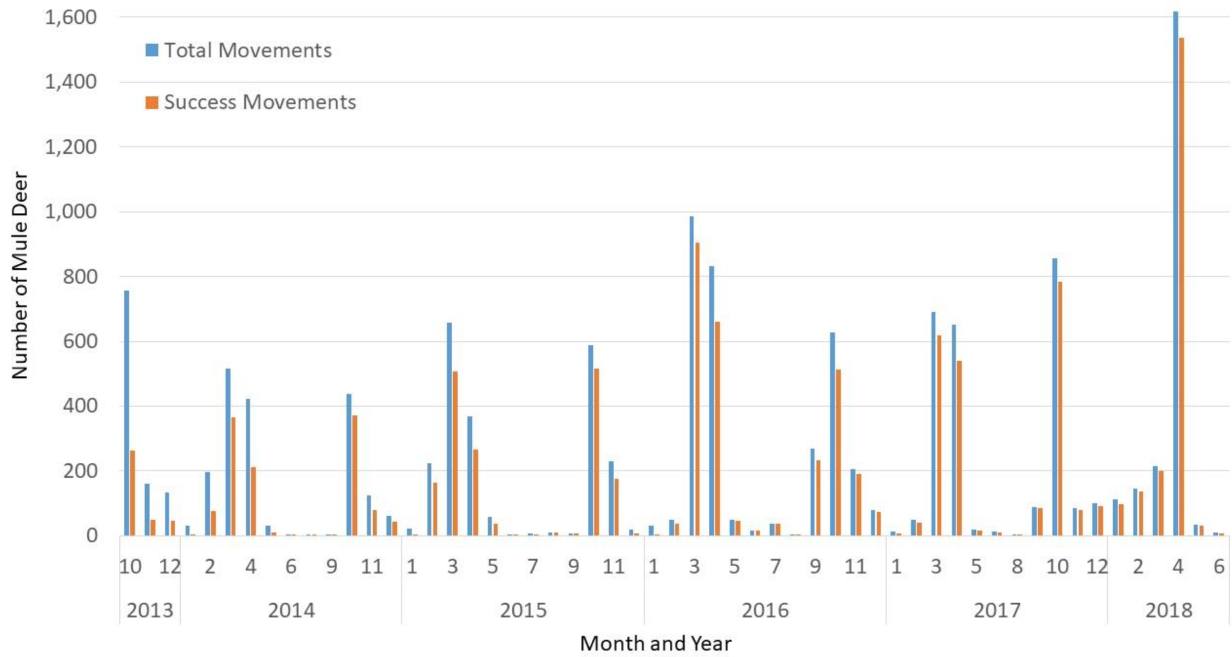

Figure 14. Monthly Mule Deer Total Movements and Success Movements at the Center New Structure from September 23, 2013 through June 7, 2018.

2.3.2.5 West New

Figure 15 presents annual mule deer Total Movements and Success Movements at the West New structure from September 23, 2013 through June 7, 2018. Annual Total Movements increased during the study, with the exception of 2014/15. Annual Success Movements steadily increased each year. Figure 16 presents monthly mule deer Total Movements and Success Movements at the West New structure from September 23, 2013 through June 7, 2018. Monthly movements peaked during the 2017 fall migration, which had approximately 50 percent more Total and Success Movements than any other migration period during the study. Movements were higher during fall migrations than during spring migrations. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rates and monthly Success Rates generally increased during the study; however, the annual Success Rate remained stable after 2015/16. The annual Success Rate increased from

53 percent in 2013/14 to 94 percent in 2017/18. Camera operation rates were 89 percent in 2018, 85 percent in 2017, and 86 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

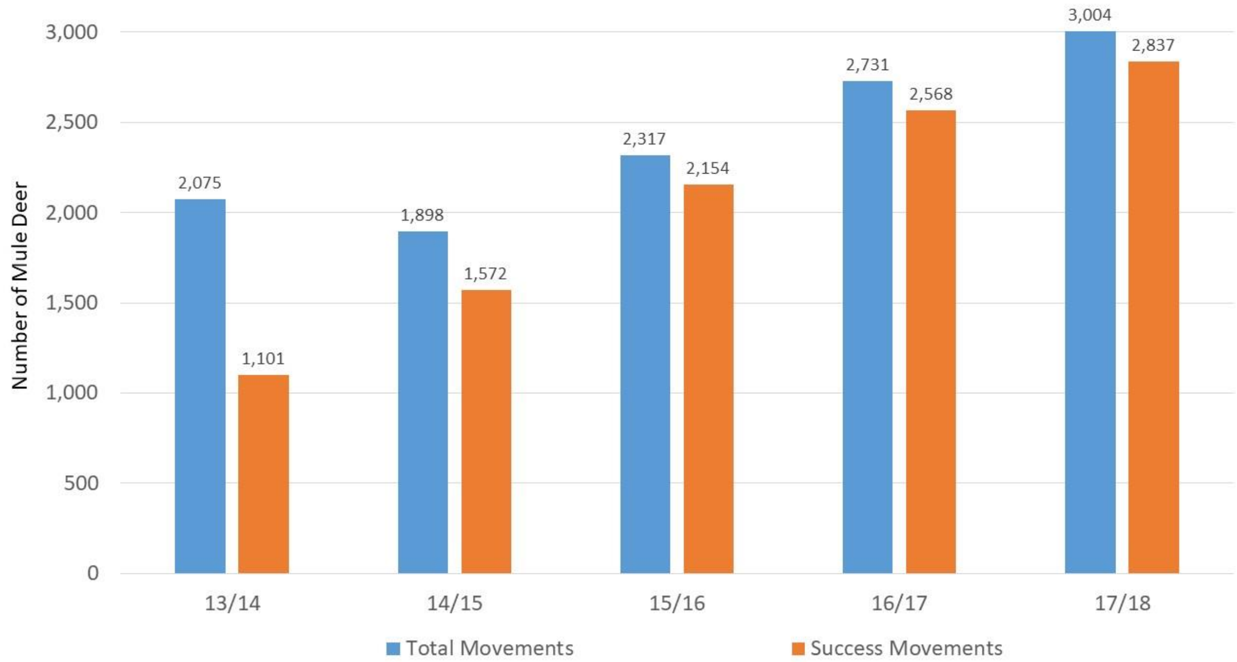

Figure 15. Annual Mule Deer Total Movements and Success Movements at the West New Structure from September 23, 2013 through June 7, 2018.

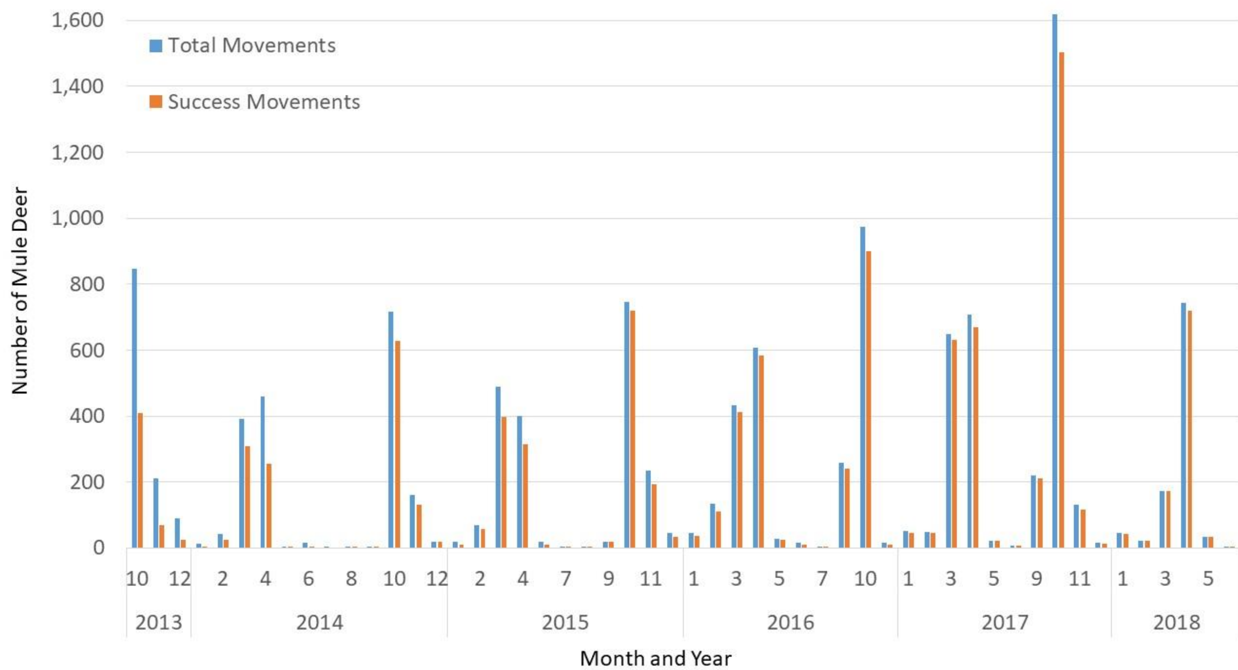

Figure 16. Monthly Mule Deer Total Movements and Success Movements at the West New Structure from September 23, 2013 through June 7, 2018.

2.3.2.6 Petrified

Figure 17 presents annual mule deer Total Movements and Success Movements at the Petrified structure from September 23, 2013 through June 7, 2018. There was a steady increase in both total number of mule deer Success Movements and Success Rate over the study. The lowest number of annual Total Movements occurred in 2014/15 and increased each year for the duration of the study. Annual Success Movements steadily increased each year. Figure 18 presents monthly mule deer Total Movements and Success Movements at the Petrified structure from September 23, 2013 through June 7, 2018. Monthly movements peaked during the 2017 fall migration. Movements were higher during fall migrations than during spring migrations, with the exception of spring 2017. As the study progressed, spring movements became greater in April than in March. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rates and monthly Success Rates increased during the study. The annual Success Rate increased from 73 percent in 2013/14 to 97 percent in 2017/18. Camera operation rates were 73 percent in 2018, 92 percent in 2017, and 100 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

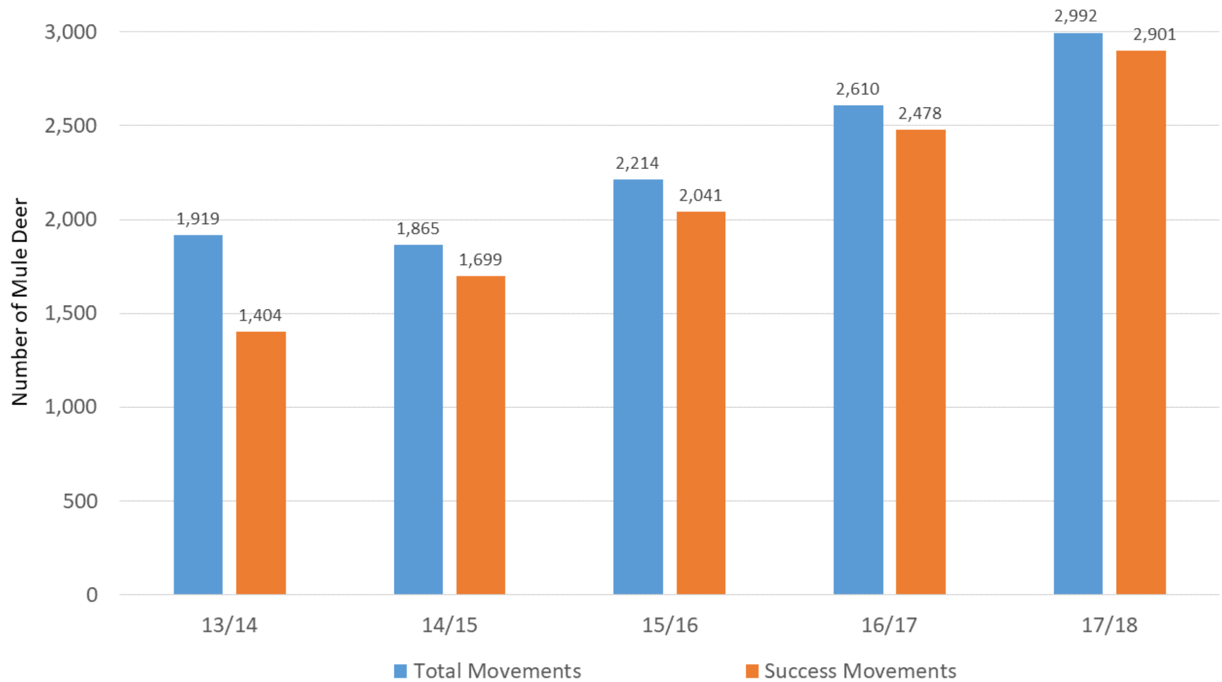

Figure 17. Annual Mule Deer Total Movements and Success Movements at the Petrified Structure from September 23, 2013 through June 7, 2018.

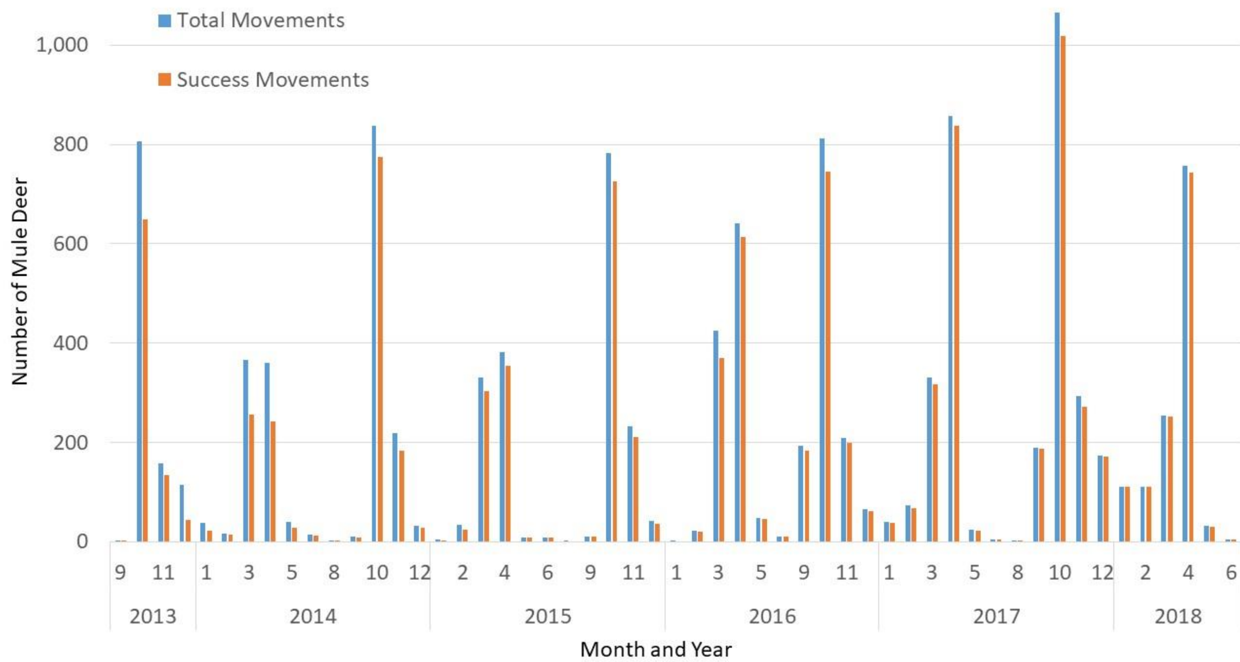

Figure 18. Monthly Mule Deer Total Movements and Success Movements at the Petrified Structure from September 23, 2013 through June 7, 2018.

2.3.2.7 Seaman

Figure 19 presents annual mule deer Total Movements and Success Movements at the Seaman structure from September 23, 2013 through June 7, 2018. Total Movements and Success Movements steadily increased through 2015/16, greatly increased in 2016/17, and decreased in 2017/18. Figure 20 presents monthly mule deer Total Movements and Success Movements at the Seaman structure from September 23, 2013 through June 7, 2018. Monthly movements generally increased during the study through 2016/17, and decreased in 2017/18. Movements during spring migrations were higher in April than in March. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rate increased after 2013/14, and then remained stable with a slight decrease in 2015/16. The annual Success Rate increased from 76 percent in 2013/14 to 92 percent in 2017/18. Camera operation rates were 100 percent in 2018, 100 percent in 2017, and 83 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

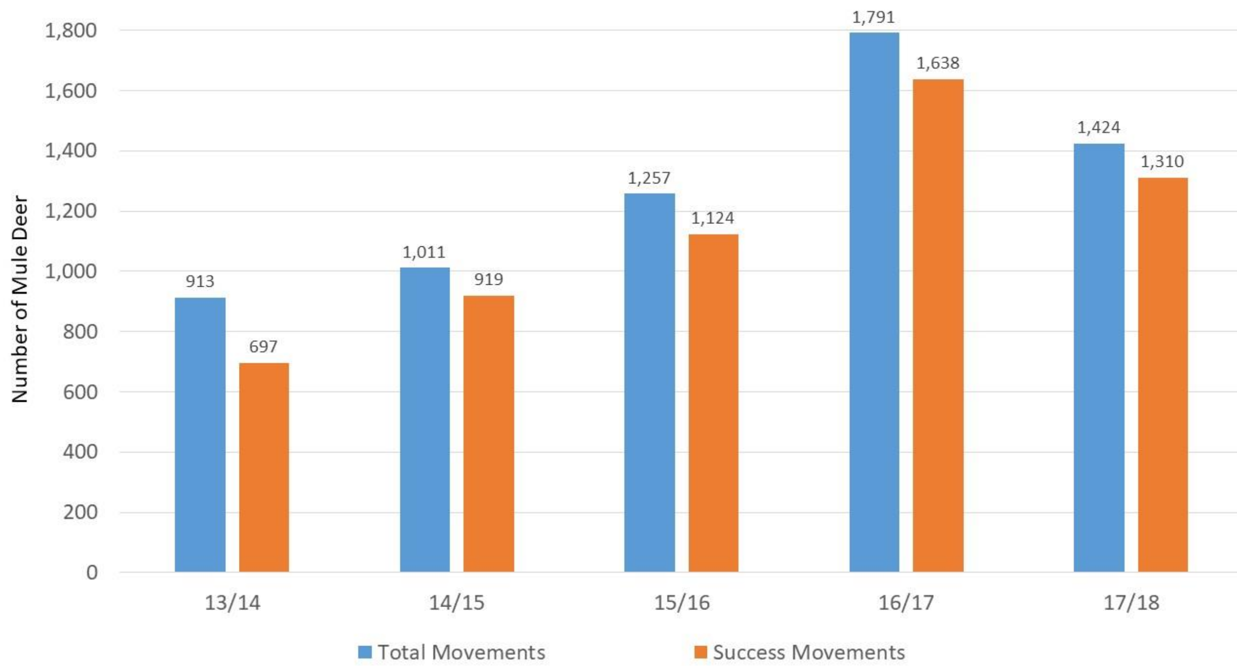

Figure 19. Annual Mule Deer Total Movements and Success Movements at the Seaman Structure from September 23, 2013 through June 7, 2018.

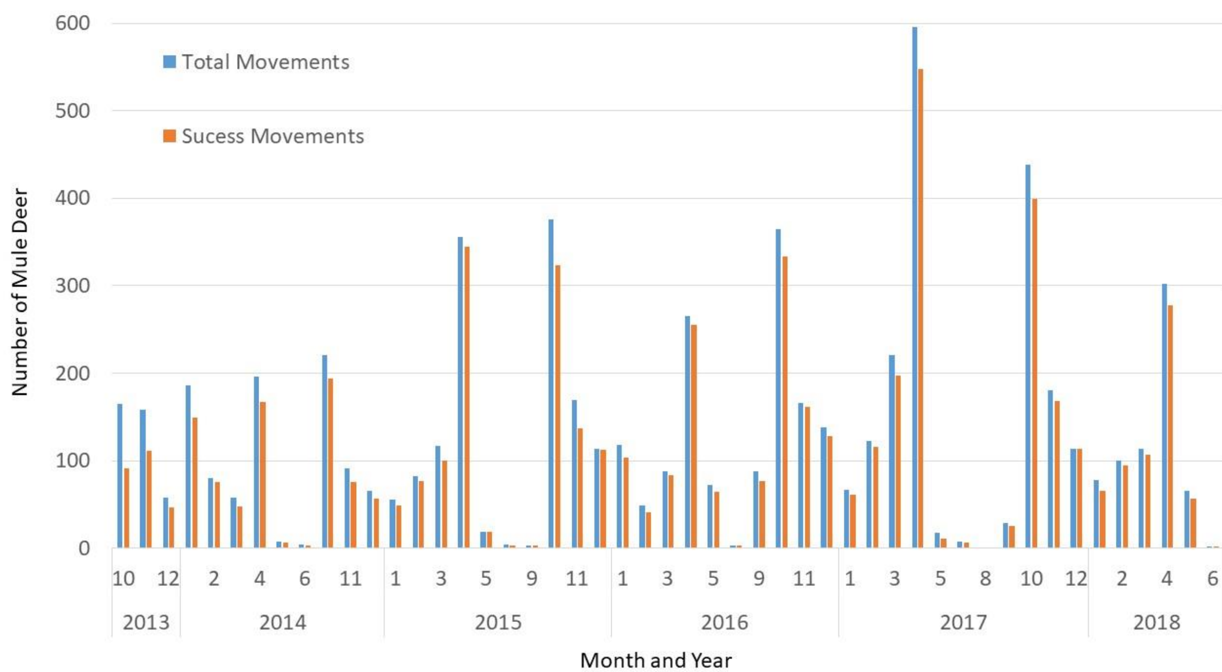

Figure 20. Monthly Mule Deer Total Movements and Success Movements at the Seaman Structure from September 23, 2013 through June 7, 2018.

2.3.3 Mule Deer Movements at Fence Ends

There were 1,438 Total Movements and 1,335 Success Movements by mule deer at the East Fence End during the study. Figure 21 presents annual mule deer Total Movements and Success Movements at the East Fence End from September 23, 2013 through June 7, 2018. Annual movements at the East Fence End decreased through 2016/17, and then increased in 2017/18. Figure 22 presents monthly mule deer Total Movements and Success Movements at the East Fence End from September 23, 2013 through June 7, 2018. Monthly movements peaked during most of the spring and fall migrations. Monthly movements were not recorded from May 2016 through February 2017 because cameras were not operating during much of this period. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Camera operation rates were 87 percent in 2018, 60 percent in 2017, and 43 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

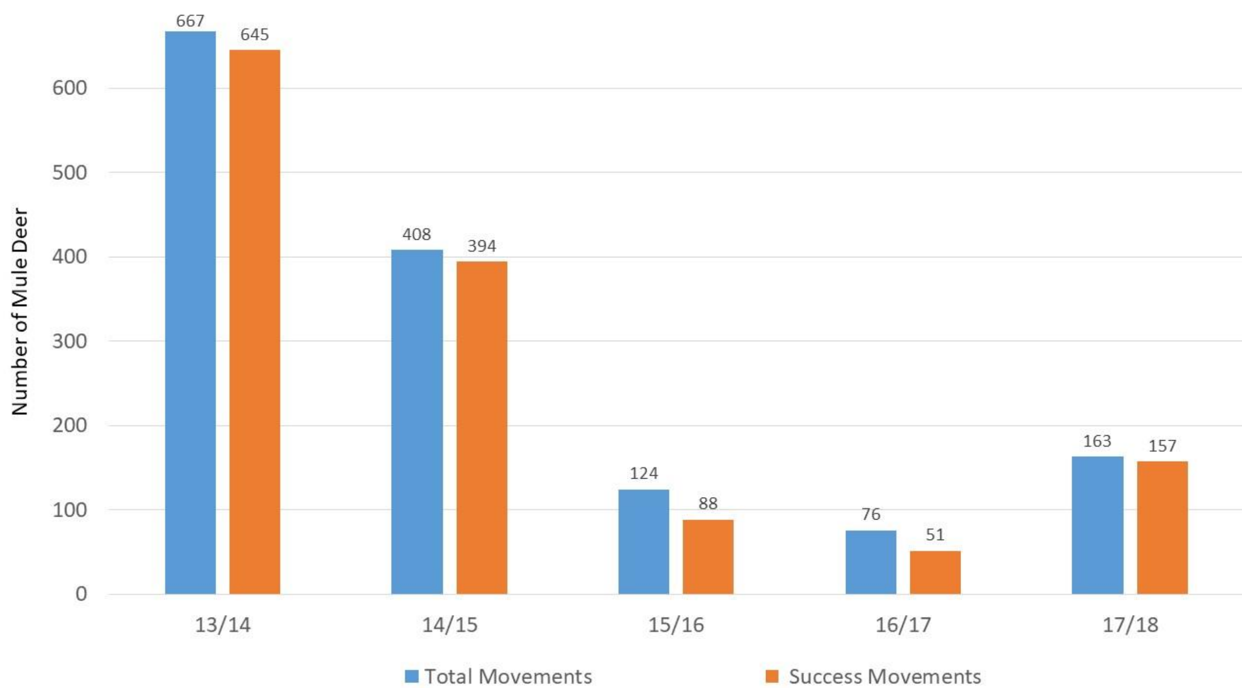

Figure 21. Annual Mule Deer Total Movements and Success Movements at the East Fence End from September 23, 2013 through June 7, 2018.

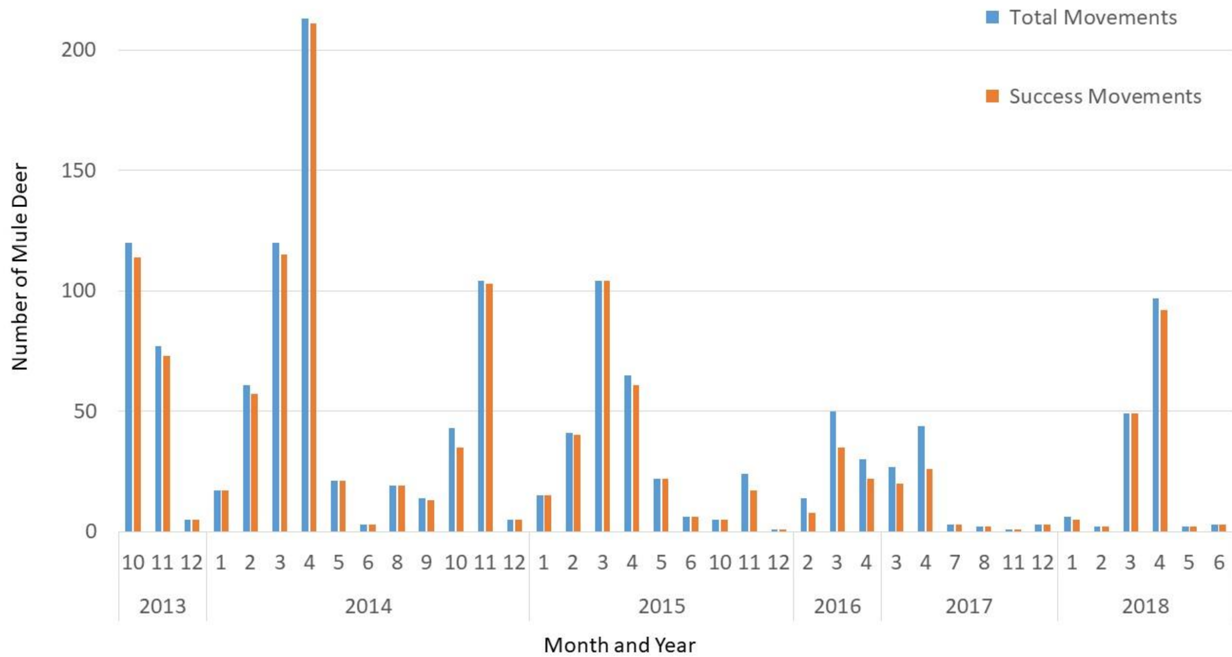

Figure 22. Monthly Mule Deer Total Movements and Success Movements at the East Fence End from September 23, 2013 through June 7, 2018.

There were 1,027 Total Movements and 907 Success Movements by mule deer at the West Fence End during the study. Figure 23 presents annual mule deer Total Movements and Success Movements at the West Fence End from September 23, 2013 through June 7, 2018. Annual movements dramatically decreased after 2013/14. Figure 24 presents monthly mule deer Total Movements and Success Movements at the West Fence End from September 23, 2013 through June 7, 2018. After the dramatic decrease in movements post 2013, overall movements peaked during the spring and fall migrations, and were greater during fall migrations than during spring migrations. For paired columns in both figures, the ratio of Success Movements (orange, right) to Total Movements (blue, left) is equal to Success Rate. The closer the values of the paired columns, the higher the Success Rate. Annual Success Rate was highest in 2015/16 (93 percent) and lowest in 2016/17 (79 percent). Camera operation rates were 100 percent in 2018, 94 percent in 2017, and 95 percent in 2016 (2015, 2014, and 2013 camera operation rates were not calculated).

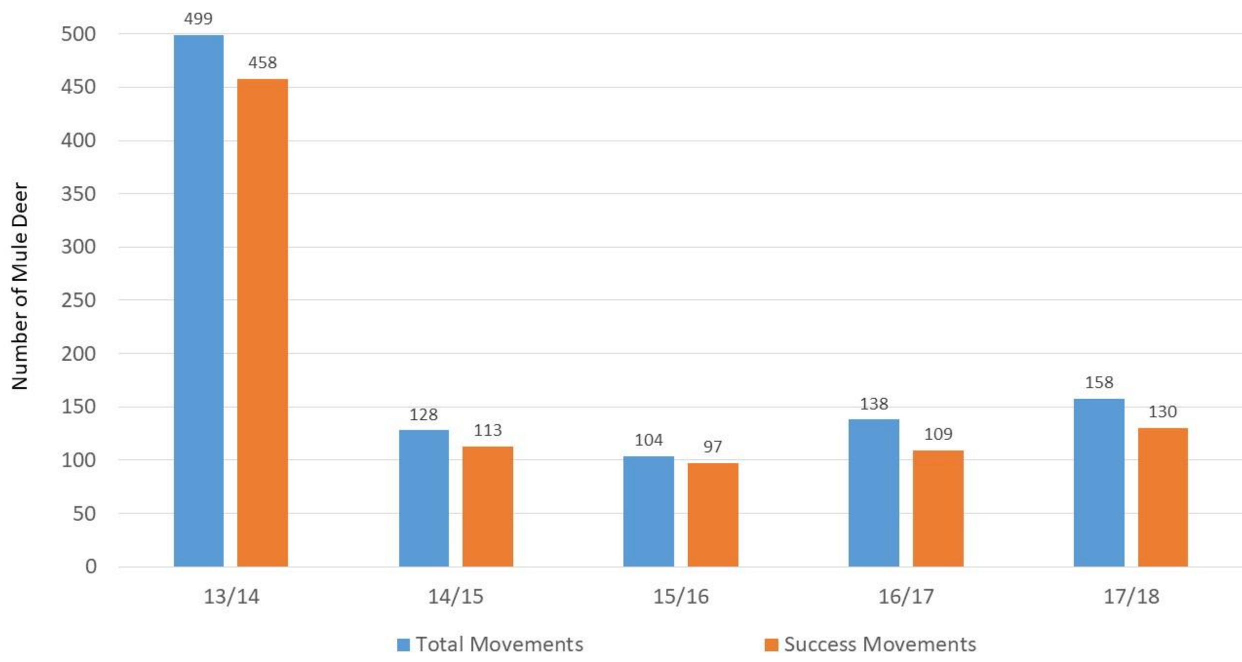

Figure 23. Annual Mule Deer Total Movements and Success Movements at the West Fence End from September 23, 2013 through June 7, 2018.

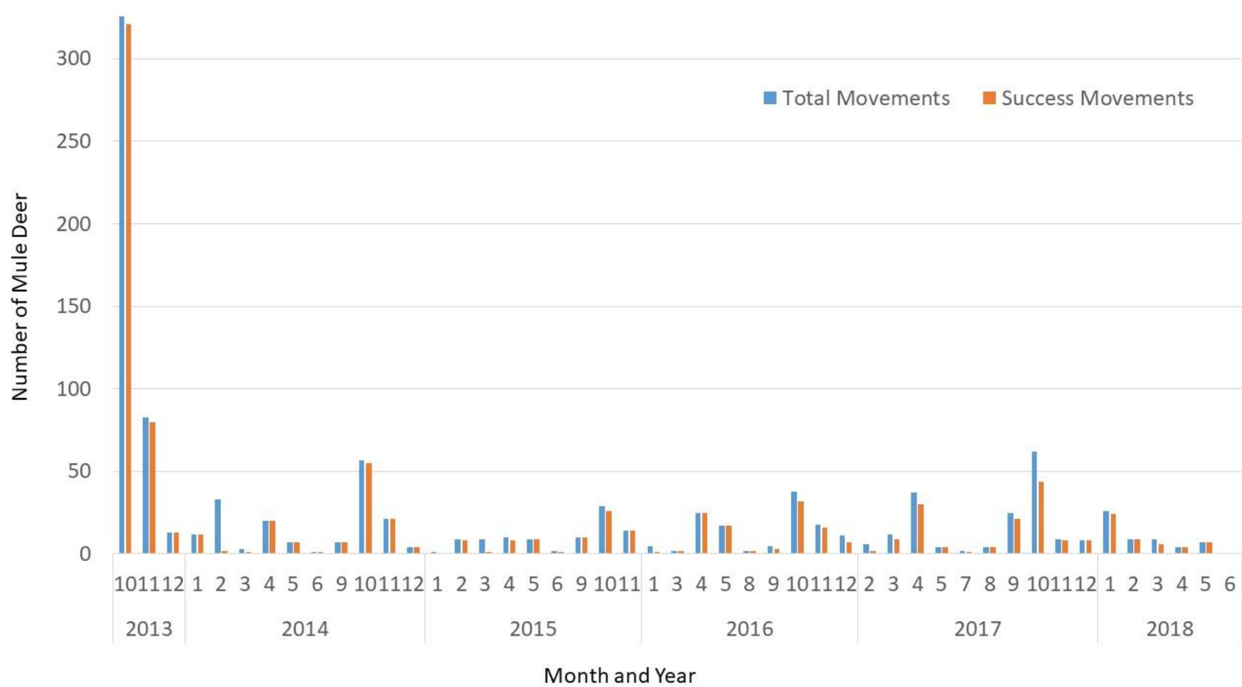

Figure 24. Monthly Mule Deer Total Movements and Success Movements at the West Fence End from September 23, 2013 through June 7, 2018.

2.3.4 Potential Relationships between Mule Deer Success Rates and Structure Heights, Widths, Lengths, and Openness Ratios

Table 3 presents length, width, height, and openness ratios in feet and in meters for the seven structures and mule deer success rates at each structure. Figure 25 presents scatter plots of overall mule deer Success Rates with structure heights, widths, lengths, and openness ratios. Mule deer Success Rate increased with increasing height, width, and openness ratio and decreased with increasing length; however, these relationships were generally weak. Logistic regression using generalized linear-mixed models was conducted for Success Rate, Rate of Repellency, and Parallel Rate with structure dimensions and Openness Ratios. The results were not reported because there were not enough data and the data poorly matched the assumptions of the logistic regression.

Table 3. Structure Dimensions, Openness Ratio, and Success Rates at Individual Structures from September 23, 2013 to June 7, 2018.

Structure Name and Mile Post (MP)	**Dimensions of Structure Height x Width x Length in Feet**	**Openness Ratio in Feet (ft) and in Meters (m)**	**Success Rate (%)**
Buckskin, MP 37	30 x 50 x 44	27.5 (ft) 8.38 (m)	89
Telegraph, MP 39.5	7.5 x 6 x 84	0.53 (ft) 0.16 (m)	25
East New, MP 40.5	8.5 x 15.6 x 52	2.53(ft) 0.77 (m)	86
Center New, MP 42.5	8.5 x 15.6 x 52	2.53 (ft) 0.77 (m)	79
West New, MP 44	12 x 18.6 x 68	3.28 (ft) 1.00 (m)	85
Petrified, MP 45.5	12 x 23 x 77	2.99 (ft) 0.91 (m)	91
Seaman, MP 48.2	12 x 24 x 75	3.84 (ft) 1.17 (m)	89

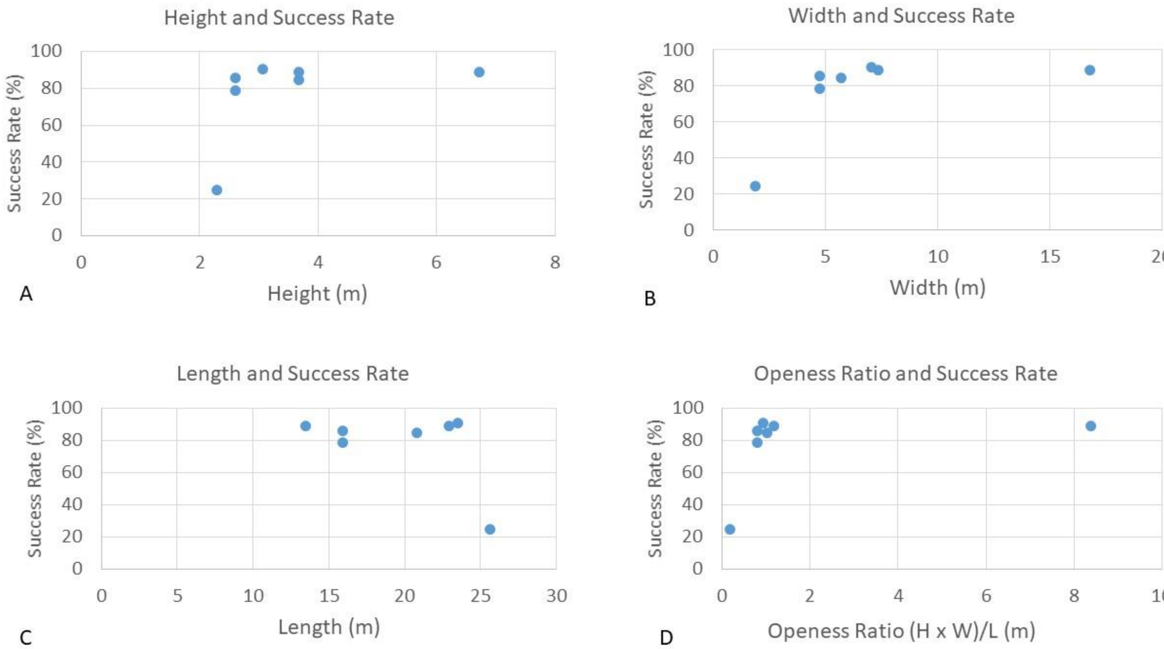

Figure 25. Scatter Plots of Mule Deer Success Rates Against: (A) Structure Height; (B) Structure Width; (C) Structure Length; and (D) Openness Ratio.

2.3.5 Mule Deer Gender and Direction of Origin

The number of mule deer success movements by gender and direction of origin are presented by seasons in Figure 26. Fall seasons were dominated by movements from the north with very few movements from the south. Spring seasons consisted of mainly movements from the south with a fair amount of movements from the north. Mule deer gender ratios remained relatively stable for all seasons and years. Females consisted of 28 to 49 percent of all movements in all seasons. Males consisted of 22 to 26 percent of all success movements most years, with a low of 15 percent in the spring migration of 2015 (when many males have no antlers) and a high of 36 percent during the fall migration of 2015. Unknown animals consisted of 30 to 50 percent of all animals over the seasons and years.

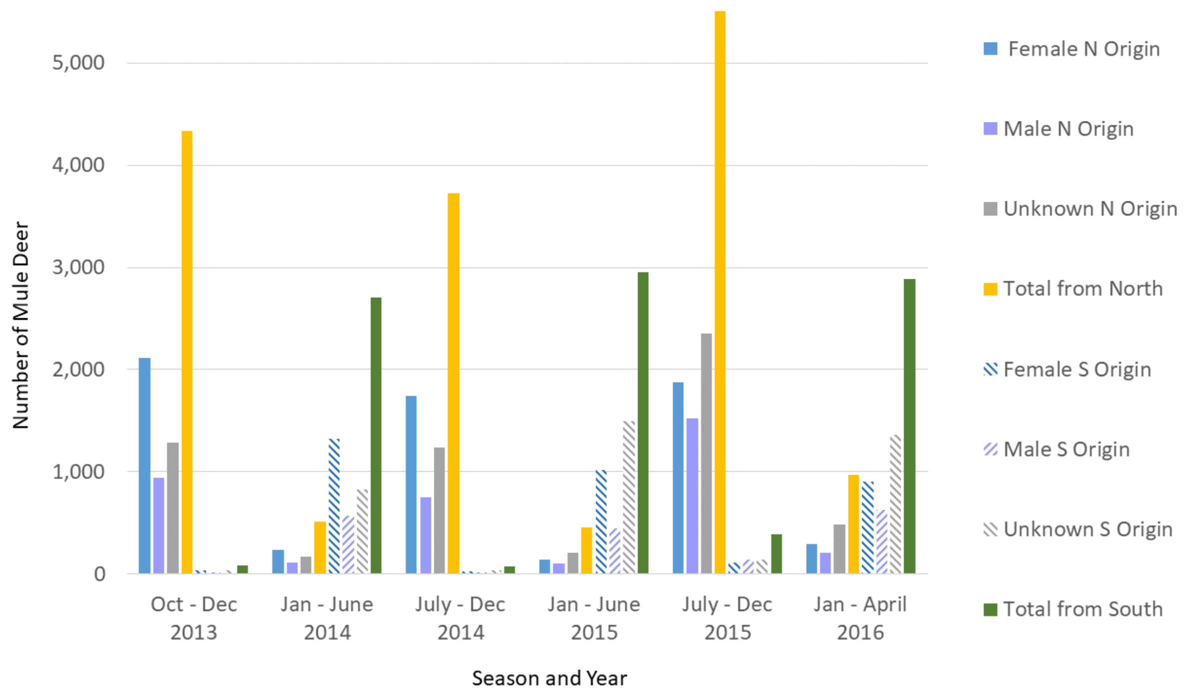

Figure 26. Mule Deer Gender and Direction of Origin of Travel of Success Movements by Season and Year, 2012-2016, N= North, S= South.

2.3.6 Elk Movements

There were 21 Success Movements made by elk through wildlife crossing structures, for a Success Rate of 40 percent. Table 4 presents Total Movements, Success Movements, and Success Rates for elk at each of the seven structures from September 23, 2013 to June 7, 2018. Buckskin had the highest number of elk Success Movements (11) and the highest Success Rate (61 percent) for structures with more than one success movement. Elk movements were recorded on 39 occasions at the wild cameras on the north side of the seven structures. Elk movements were also recorded on nine occasions at the fence ends. Elk Success Movements through structures were made by non-antlered animals (most likely cows and calves), with the exception of one success movement through Buckskin by a male elk. Male elk were observed on two occasions at fence ends.

Table 4. Elk Movements and Success Rates from September 23, 2013 to June 7, 2018.

Structure Name and MP	Total Movements	Success Movements	Success Rate (%)
Buckskin, MP 37	18	11	61
Telegraph, MP 39	13	0	0
East New, MP 40.5	7	2	29
Center New, MP 42.5	4	2	50
West New, MP 44	1	1	100
Petrified, MP 45.6	9	5	56
Seaman, MP 48	0	0	0
Totals	**52**	**21**	**40**

2.3.7 Other Wildlife Species

Other wildlife species successfully moved through the wildlife crossing structures during the study. Table 5 presents Total Movements and Success Movements by additional mammal wildlife species. The overall Success Rate for carnivores was 80 percent. Pronghorn antelope were observed only at the Buckskin structure.

Table 5. Other Wildlife Species Total Movements and Success Movements.

Species	Total Movements	Success Movements
Jack Rabbit	4,382	2,165
Badger	73	61
Black Bear	1	1
Bobcat	676	561
Coyote	1,931	1,456
Mountain Lion	49	38
Pronghorn Antelope	14	2

2.4 Discussion

2.4.1 Mule Deer Movements Study-Wide

The US 89 Kanab-Paunsaugunt project is one of the most successful mule deer mitigation projects in all of North America; 78,610 mule deer Success Movements through seven structures were documented in five years. A comparable mitigation project was Nugget Canyon, Wyoming where approximately 49,000 mule deer Success Movements through seven structures were documented in three years (Sawyer and LeBeau 2011). The success of the Kanab-Paunsaugunt project was also validated by its overall annual Success Rates of all structures that increased from 44 percent in 2013/14 to 92 percent in 2017/2018.

In this study, individual mule deer movements were tallied, not individual mule deer. Clearly, individual mule deer are moving through the structures on multiple occasions. Annual Success Movements increased each year of the study by an average of 30 percent (Figure 2). The number of mule deer movements cannot be used to estimate the Paunsaugunt mule deer population size. We can say that the number of mule deer movements recorded by the cameras increased; however, we cannot say that the number of individual mule deer increased. UDWR estimates for the Paunsaugunt mule deer management area increased 15 percent from 5,200 in 2013 to 6,000 in 2017.

Mule deer utilized the seven structures throughout the year, with increased use during migration periods. Figure 5 demonstrates that mule deer movements peaked during the migration periods. However, mule deer movements occurred in every month of the year and at the tail ends of migrations. Figure 5 reveals that the number of mule deer movements during spring migrations were greater and occurred over longer durations than fall migrations. However, we cannot assume that the number of individual mule deer that migrated in the spring was greater than the number of individual mule deer that migrated in the fall of each year. The greater numbers in the spring indicate the individual mule deer moved back and forth through the structures more during spring migrations than during fall migrations. Mule deer follow the "green-up" of forage each spring and utilize "stopover" locations (Sawyer and Kauffman 2011). Photographic analysis in this study revealed that mule deer migrations are not simply a linear progression; rather migrations are pulsed, and on occasion temporarily reversed. Figure 5 also demonstrates that the number of mule deer movements increased during the fall migrations of 2016 and 2017, and that their durations increased compared to previous fall migrations.

2.4.2 Mule Deer Movements at Individual Wildlife Crossing Structures

Table 2 and Figure 5 demonstrate that the East New wildlife crossing structure at MP 40.5 worked extremely well to facilitate mule deer Success Movements. The East New structure had more than two times the number of mule deer Success Movements (25,355) compared to all other structures. It appeared that mule deer chose this structure based on its location within the landscape rather than its physical dimensions or construction type; the three new structures have similar dimensions and the same construction type (Table 1). Previous research (Carrel et al. 1999, Messmer and Klimack 1999) and the crash data (detailed below) support the statement that prior to the mitigation, mule deer crossed US 89 more heavily in the area of Telegraph Wash from MP 39 to 40 than any other segment of US 89 in the study area. Thus, it was expected that mule deer would use structures in this general area more heavily than other places along US 89.

Table 2, and Figures 5 and 6 demonstrate that the Telegraph structure did not work as well as the other structures. Telegraph had the smallest size, by far, compared to the other structures. It appeared mule deer chose not to use this structure based on its dimensions rather than its location within the landscape; Telegraph had the second highest number of Total Movements over the course of the study (16,021), yet the smallest number of total Success Movements (4,056). However, annual Success Rates at the Telegraph structure increased each year of the study. Annual Success Rate and annual Success Movements increased dramatically in 2017/18. These increases at Telegraph occurred at the same time Annual Success Rate decreased slightly at Buckskin.

Mule deer choices not to use the Telegraph structure may have partially contributed to the high numbers of annual Success Movements at the adjacent East New structure. Annual mule deer Success Movements increased at Buckskin and East New while Total Movements decreased at Telegraph (Figures 5, 9, and 10). East New and Buckskin geographically straddle Telegraph, historically the most highly traveled area by Paunsaugunt mule deer prior to the mitigation, according to local UDOT personnel (S. Ramsey), and prior studies (Carrell et al. 1999, Messmer and Klimack 1999). It is important to note that annual Success Rates and annual Success Movements at Telegraph did not stabilize, and that annual Success Movements increased 332 percent between 2016/17 and 2017/18. The five years of monitoring allowed for the research to demonstrate the time it took for a portion of the mule deer herd to adapt to and use the Telegraph structure.

The other five structures generally worked well with similar numbers of mule deer Success Movements and Success Rates. The Seaman structure was an exception, and had lower Success Movements. It is interesting to note that the Success Rates of the six structures other than Telegraph had Success Rates that began to converge on a range of 90 to 97 percent in the final year of the study (Figure 6).

2.4.3 Adaptive Management

On multiple occasions during the study, cameras recorded BLM grazing allotment holders placing fences or gates across the Buckskin, Telegraph, and Petrified structures to manage their cattle. Cameras also recorded occasions when the fences were removed. It is important to note that the cameras may not have recorded all fence placement and removal situations. While in place, the fences temporarily deterred mule deer use of the structures and caused short-term reductions in Success Rates. These situations were occasionally rectified with adaptive management. Wildlife-friendly fence (Harrington and Conover 2006) constructed in appropriate locations away from structures will increase Success Movements through the structures, increase Success Rates, and will help prevent animals from becoming entangled in fences. The authors recommend that UDWR and BLM work together to build a better fence solution at the Buckskin Bridge. The following list provides a timeline for each structure:

2.4.3.1 Buckskin

- From December 29, 2013 to March 18, 2014, a five-foot fence was placed across the south side of the structure. During this period, the mule deer Success Rate decreased from 88 percent to 42 percent. On March 18, 2014, the top strand of wire was removed by UDOT.
- On April 8, 2014, UDWR and BLM built a more wildlife-friendly four-foot fence across the structure. From March 18, 2014 to April 8, 2014 the success rate was 75 percent.
- From April 8, 2014 to July 11, 2014 the success rate was 31 percent.
- On July 11, 2014, a flood pulled down the fence.
- A three-strand four-foot fence was placed across the structure on October 3, 2014 by BLM. The success rate from July 11, 2014 to October 2, 2014 was 72 percent.
- The success rate from October 3, 2014 to December 10, 2014 was 93 percent.
- A fence went up October 26, 2015. Cows broke the fence on November 2, 2015. The fence was up again on November 11, 2015.
- The fence was put up again on December 10, 2015. It came down sometime in January, 2016.
- The fence was put up on Feb 21, 2017.
- Spring 2017 researchers recorded a mule deer carcass entangled in this fence, Figure 27.
- The fence was put up on October 16, 2017. It came down sometime in the fall.
- The fence was put up on December 6, 2017.
- The fence was up from April 11, 2018 through the end of the study, resulted in hundreds of repellency movements, and may explain the increase in mule deer moving around the East Fence End during this period.

Figure 27. Wire Fence for Domestic Cattle Attached to the South End of the Buckskin Structure in 2018 with Mule Deer Carcass Tangled In Barbed Wire.

2.4.3.2 Telegraph

- A gate was placed on the south end of the structure from April 11, 2014 through April 16, 2014. During this period, 280 mule deer repellency movements and one success movement were recorded. UDWR and BLM biologists worked with the cattle managers to take the gate down and keep it removed.

2.4.3.3 Petrified

- A gate was placed across the inside of the structure in November of 2013. Two weeks prior to the gate placement, the rate of repellency was 19 percent. Two weeks after the gate placement, the rate of repellency increased to 75 percent. UDWR and BLM worked with the cattle managers to ask them to remove the gate, which they did.
- UDWR constructed a wildlife-friendly rail fence in 2016 (Figure 28) on the south side of the culvert.

Figure 28. Wildlife Friendly Fence Installed by UDWR Wildlife Biologists on South Side of Petrified Culvert.

2.4.4 Potential Relationships between Mule Deer Success Rates and Structure Heights, Widths, Lengths, and Openness Ratios

Logistic regression results were not reported because there was not enough data and the data poorly matched the assumptions of the logistic regression. In Figure 25, five structures were clumped and two structures were two outliers (Telegraph and Buckskin). Telegraph had the greatest length and the least height and width, while Buckskin had the least length and the greatest height and width. The residuals in these three plots are not close to being equal, thus the data were not normally distributed.

2.4.5 Mule Deer Gender, Origin of Travel, and Seasons

Mule deer gender and origin of travel were recorded from September 2013 into April 2016. Several trends in the data merit mention. Mule deer bucks when they were best identifiable, in the fall months, consistently represented 20 to 26 percent of all mule deer success movements.

This is not necessarily the percentage of male mule deer in the population, but could be correlated with UDWR targets. The fall migration periods typically had a stronger movement affinity from the north. The spring migrations while predominantly from the south, appeared to have greater percentages of total movements from the less predominant direction, the north, than the predominance of movements from the south during the fall. It is important to note that animal movements across US 89 did not consistently occur in the same places between seasons and among years. It is also important to note there were multiple back and forth movements by animals over short periods of time, thus some animals were counted as success movements multiple times in a single day or season.

2.4.6 Elk Movements and Other Wildlife Species

The wild cameras placed on the north side of every structure recorded animals that may have been in the area of the road but did not come near the structure entrances. This was an effort to see if the structures were providing potential connectivity for these more road-shy animals. Thirty-nine elk were recorded by wild cameras. Fifty-two elk movements were recorded at structure entrances; twenty-one of these movements were Success Movements. It appeared the elk in the wild areas approached the structures to some degree. The overall success rate of 40 percent was similar to overall elk success rates at structures across Utah, 45 percent (Cramer 2014). Several structures (particularly Buckskin) provided some permeability (61 percent Success Rate) for elk during the study. Buckskin also provided very limited permeability for pronghorn antelope (14 percent Success Rate, 2 Success Movements). Relative to the number of mule deer movements recorded within the project, the number of elk movements and pronghorn antelope movements were very low. The structures worked well for carnivores and jack rabbits.

3.0 ANALYSES OF WVC CRASH AND MULE DEER DATA TO EVALUATE REDUCTION IN WILDLIFE-VEHICLE CRASHES IN THE STUDY AREA

3.1 Overview

A thorough evaluation of the effectiveness of a wildlife mitigation project includes the analyses of reported crashes with wild animals in the study area and in adjacent control sections during Pre-Construction and Post-Construction years. This chapter presents the results of analyses of 2009-2017 UDOT reported crashes with wild animals.

3.2 Methods

Utah reported WVC crash data for the years 2009 through 2017 were received from Clancy Black, consultant to UDOT. Data for US 89 from MP 30 through 56 were filtered and parsed into four years of Pre-Construction (2009-2012) and four years of Post-Construction (2014-2017) categories. The 2013 crash data were categorized as Construction Period because construction of the wildlife exclusion fence occurred during this year, and thus were not used in analyses. The UDOT WVC crash data were reported to the nearest 0.01 mile (0.16 kilometers). We rounded to the nearest 0.1 mile, 0.5, or 1.0 mile, (0.16, 0.80, or 1.61 kilometers) depending on the analysis or presentation of WVC crash data. Over 95 percent of wild animal crashes in Utah are with mule deer, so it was assumed this would be true for US 89.

US 89 was divided into three sections for analyses: The East Control Section (MP 30.0 to 36.1), the Mitigation Section (MP 36.2 to 48.6), and the West Control Section (MP 48.7 to 56.0). The beginning and end of the fence in the Mitigation Section were the dividing lines between the Mitigated Section and the East and West Control Sections. Crash rates were calculated for Pre-Construction and Post-Construction periods for each of the three sections. The changes in crash rates between Pre-Construction and Post-Construction were also calculated for each of the three sections.

Before-After-Control-Impact (BACI) analyses were conducted to determine if the mitigation (structures and wildlife fence) reduced the WVC crashes in the Mitigation Section. BACI analyses controlled for variables that changed during the study. These variables included traffic volume, mule deer population, and other landscape-scale variables that directly affect crash rates.

Recognizing the possibility of spatial autocorrelation, we estimated autocorrelation at multiple distances for Pre-Construction WVC counts. Although there was minimal evidence of autocorrelation at most distances, the cyclical pattern of autocorrelations suggested that some WVC may have been allocated to 0.5 mile (0.80 kilometers) road segments. Thus, we used WVC counts to the nearest 0.5 mile (0.80 kilometers) as the response in our BACI analysis. We compared WVC crash rate differences before and after construction among the three road sections (East Control Section, Mitigation Section, and West Control Section) using a generalized linear-mixed model with a Poisson distribution and a log link, blocking on-road segments and with section and time (Pre-Construction and Post-Construction) as fixed effects factors. Multiple contrasts among interaction effects were controlled for Type I error using the Tukey method.

We used the lme4 package (Bates et al., 2015; version 1.1-18-1) to fit the statistical model; the car package (Fox and Weisberg, 2011; version 3.0-2) to estimate Type III tests of significance; and the emmeans package (Lenth 2018; version 1.2.3) to estimate marginal means and contrasts in R (R Core Team, 2018; version 3.5.1).

WVC carcass data were retrieved from the Utah AGRC Website: https://mapserv.utah.gov/wvc/desktop/ . Carcass data collection and reporting were completely unreliable relative to reported crash data, thus carcass data were not used in the analyses. Several examples follow. There were 73 reported carcasses at MP 43.0 in 2009, 2010, and 2011 while there were little to none reported for five miles (eight kilometers) in either direction from that MP. Carcass numbers were generally less than crash numbers for a given time and space. For example, two carcasses and 12 crashes were reported in the Mitigation Section in 2015. From

MP 36 to MP 56 there were zero carcasses and 15 crashes reported in 2017. A comparison of UDOT WVC crash data and WVC carcass data during Pre-Construction and Post-Construction is presented in Appendix C.

Traffic volume on US 89 for the 26 miles (41.8 kilometers) of analyses was estimated from UDOT Average Annual Daily Traffic (AADT) estimates found on the UDOT data portal (https://data-uplan.opendata.arcgis.com/datasets/aadt-open-data).

Bill James of UDWR provided annual Paunsaugunt mule deer population estimates.

3.3 Results

The number of reported WVC crashes in each of the three sections of US 89 during Pre-Construction and Post-Construction are presented in Table 6.

Table 6. Reported Wildlife-Vehicle Collision Crashes in Each section of US 89 during Pre-Construction (2009-2012) and Post-Construction (2014-2017).

East Control MP 30.00 – 36.1		**Mitigation Section MP 36.2- 48.6**		**West Control MP 48.7 – 56.0**	
Pre-Construction	Post-Construction	Pre-Construction	Post-Construction	Pre-Construction	Post-Construction
11	14	38	18	24	54

Figure 29 presents WVC crashes per 0.5 mile (0.80 kilometer) during Pre-Construction and Post-Construction at each of the three US 89 sections. Table 7 displays WVC crash rates (crashes/year/mile) during Pre-Construction and Post-Construction periods and changes in crash rates between Pre-Construction and Post-Construction at each of the three US 89 sections. The changes in the number of Pre-Construction and Post-Construction WVC crashes differed among road sections ($p < 0.001$, Figure 29). The crash rate at the West Control Section increased by 125 percent between Pre-Construction and Post-Construction. The crash rate at the Mitigation

Section decreased by 53 percent between Pre-Construction and Post-Construction. The crash rate at the East Control Section increased by 27 percent between Pre-Construction and Post-Construction.

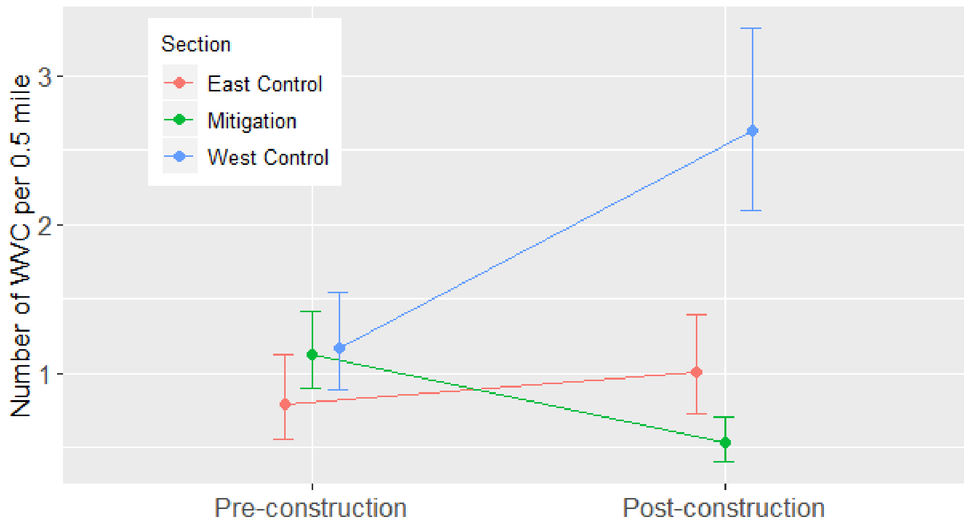

Figure 29. WVC Crashes per 0.5 Mile (0.80 kilometers) During Pre-Construction and Post-Construction at the East Control Section, Mitigation Section, and West Control Section.

Table 7. WVC Crashes Per Mile Per Year During Pre-Construction 2009-2012 and Post-Construction 2014-2017 and Overall Changes in Crash Rates in East Control, Mitigation, and West Control Sections.

Time Period	**Dates**	**East Control MP 30.00 – 36.1**	**Mitigation Section MP 36.2- 48.6**	**West Control MP 48.7 – 56.0**
Pre-Construction	2009 -2012	0.45	0.76	0.81
Post-Construction	2014 -2017	0.57	0.36	1.82
		Change = 0.12	Change = -0.40	Change = 1.01

There was no evidence that the change in crash rates between Pre-Construction and Post-Construction differed between the East Control and West Control segments ($p = 0.227$, Type I-adjusted $p = 0.449$). The Pre-Construction to Post-Construction change in crash rates differed between West Control and Mitigation ($p < 0.001$, Type I-adjusted $p = 0.001$). The Pre-Construction to Post-Construction change in crash rates likely differed between East Control and Mitigation ($p = 0.046$, Type I-adjusted $p = 0.112$). Overall, there was good evidence that the wildlife crossing structures and wildlife exclusion fence had an effect on the crash rate within the mitigation section.

Figures 30 demonstrates Pre-Construction WVC crash data by mile post in each US 89 section. Figure 31 demonstrates Post-Construction WVC crash data by mile post in each US 89 section. Figure 32 presents all crash data for each mile post during Pre-Construction and Post-Construction across all sections.

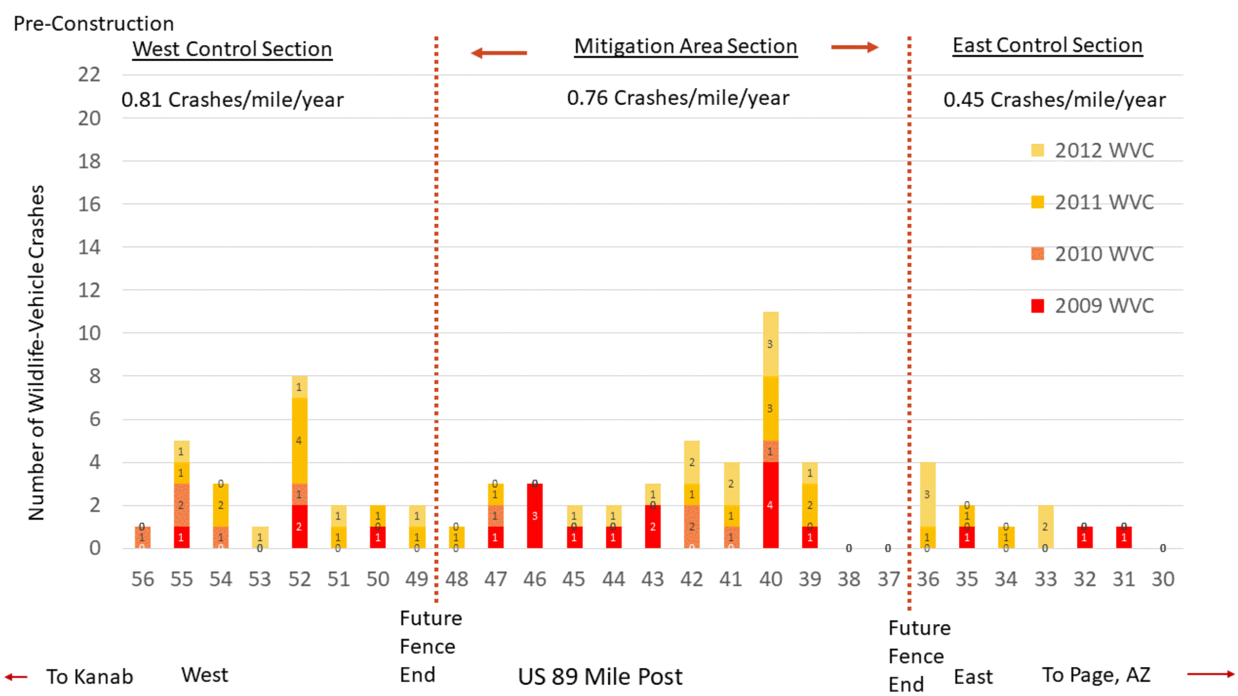

Figure 30. Utah Department of Transportation WVC Crash Data Pre-Construction, US 89 MP 30-56, 2009 -2012.

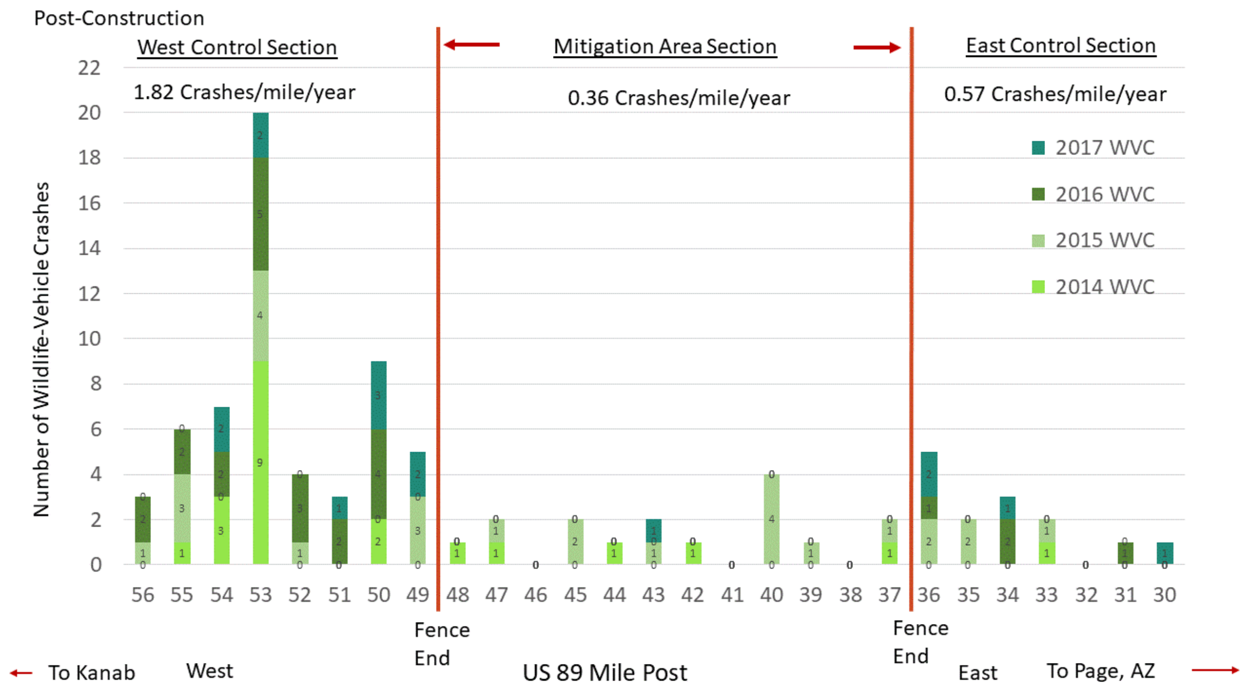

Figure 31. Utah Department of Transportation WVC Crash Data Post-Construction, US 89 MP 30-56, 2014-2017.

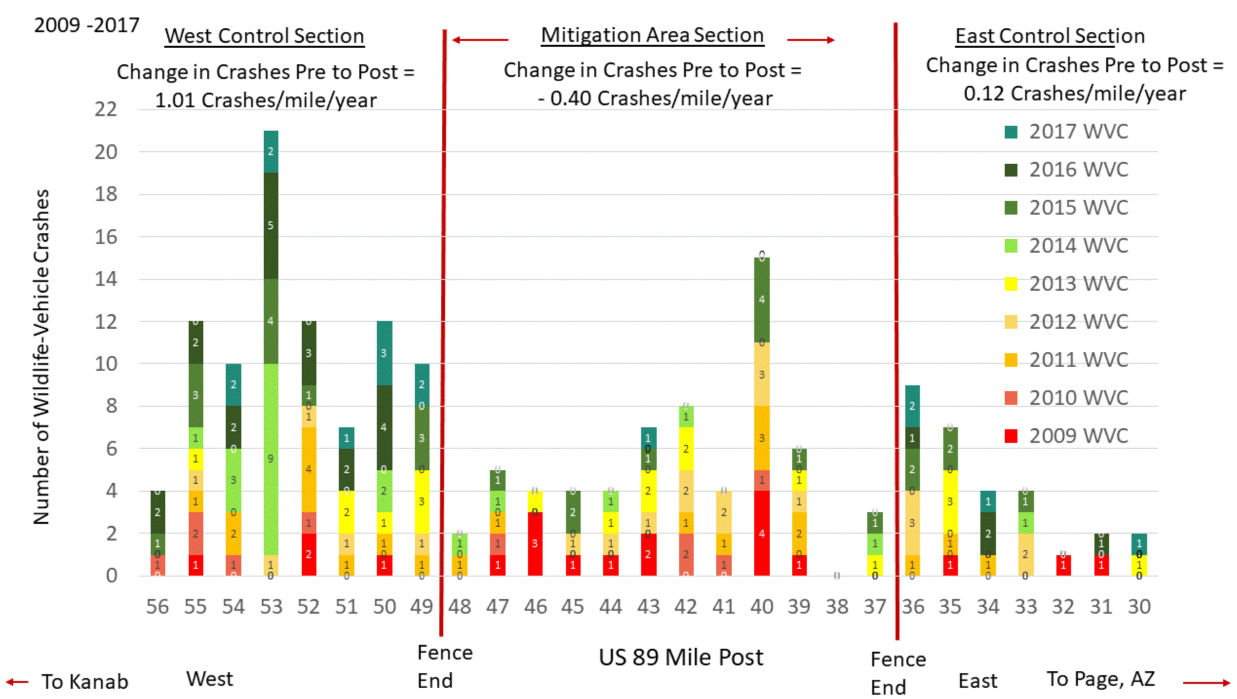

Figure 32. Utah Department of Transportation WVC Crash Data, US 89 MP 30-56, 2009 - 2017.

The UDOT estimated Annual Average Daily Traffic (AADT) for the 26 mile (41.8 kilometers) stretch of US 89 for the years 2008 through 2017 were plotted with the UDWR annual estimates of the Paunsaugunt mule deer herd for 2008-2017 in Figure 33. The estimated mule deer population increased 15 percent and the estimated AADT increased 47 percent during Post-Construction, 2014 through 2017.

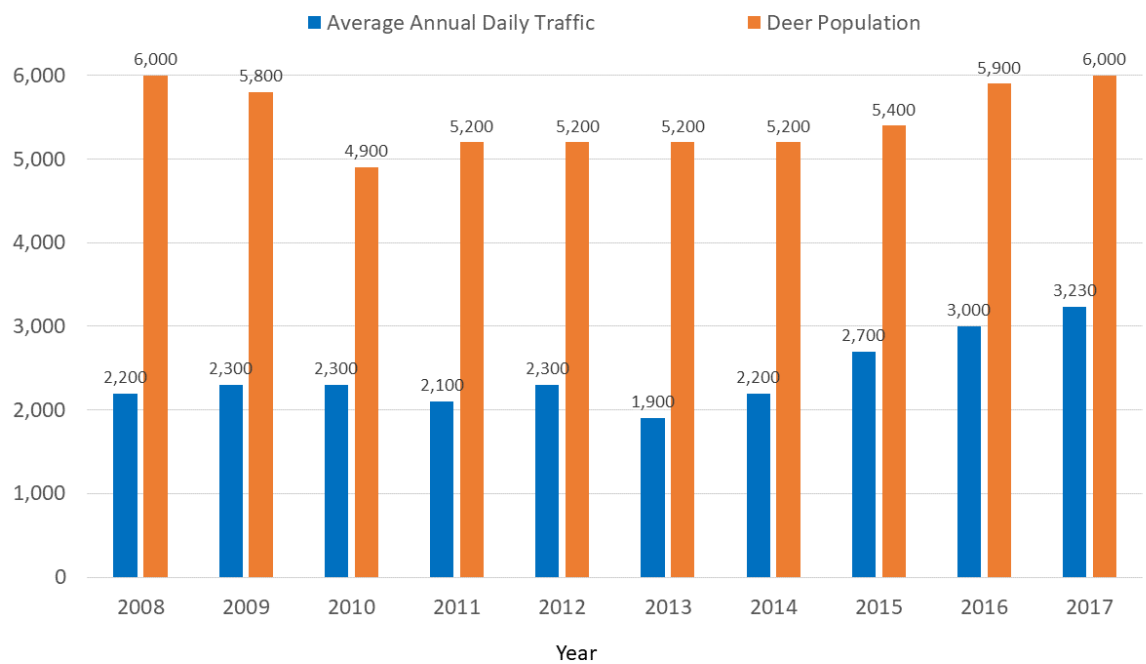

Figure 33. Annual Number of Mule Deer Estimated by UDWR in Paunsaugunt Herd and UDOT Estimated Annual Average Daily Traffic (AADT) on U.S. 89, Mile Post 30 – 54, 2008 - 2017.

3.4 Discussion

The BACI analyses of changes in WVC crash rates between Pre-Construction and Post-Construction at the Mitigation and Control Sections provided strong evidence that the wildlife crossing structures and wildlife exclusion fence decreased the crash rate within the Mitigation

Section. The decreased crash rate (53 percent), increased mule deer population (15 percent), and increased traffic volume (47 percent) in the Mitigation Section strongly support this conclusion.

BACI analyses controlled for changes in traffic volume, mule deer population, and other landscape-scale variables that directly affected crash rates. However, BACI analyses did not control for potential shifts in the mule deer population within the study area. It is possible that a portion of the mule deer population moved their migrations and activities to the west of the Mitigation Section during Post-Construction, as evidenced by the large increase in the crash rate in the West Control Section during Post-Construction. This possibility is countered by the fact that mule deer success movements through the structures increased every year during the study (Figures 8 and 9). Increasing mule deer movements are related to actual mule deer population numbers, however movements are not an estimate of population. Additionally, mule deer movements at the West Fence End did not increase during the study; and mule deer movements at the East Fence End were greater than mule deer movements at the West Fence End (Figures 25 and 27). Another explanation for the large crash rate increase in the West Control Section during Post-Construction is the fact that the crash rate in the West Control Section (0.81 crashes/year/mile) was higher than the crash rate in the Mitigation Section (0.76 crashes/year/mile) during Pre-Construction. Anecdotally, the West Control Section experienced a degree of increased human development and increased irrigation during the study. It is possible that the increase in the mule deer population, the increase in the traffic volume, and the increase in development and irrigation, combined to make the existing crash rate in the West Control Section an even greater problem, with or without any shifts in mule deer migrations.

Review of the Post-Construction WVC crash data revealed there was an increased problem of WVC crashes on US 89 near MP 53. Additional actions are needed to reduce mule deer-vehicle collisions in this area near Johnson Canyon Road.

4.0 CONCLUSION: EVALUATION OF THE EFFECTIVENESS OF MITIGATION WITH RESPECT TO PERFORMANCE MEASURES

4.1 Overview

The study determined US 89 mitigation effectiveness based on its fulfillment in meeting five performance measures: 1. Mule deer Success Movements will increase over time until there is a plateau; 2. Mule deer Success Rates through each of the newly created wildlife crossing structures will be at minimum comparable with past Utah studies, 77 percent (Cramer 2112, 2014); 3. Over time there will be a reduction in mule deer numbers moving around the ends of the fence; and 4. There will be a decrease in wildlife-vehicle collisions in the study area.

4.2 Mule Deer Success Movements

Mule deer Success Movements increased overall each year and generally with each wildlife crossing structure (Figures 3 through 5). The study met this performance measure. The annual mule deer Success Movements have not yet plateaued.

4.3 Mule Deer Success Rates

All the newly built wildlife structures had mule deer Success Rates over 90 percent by the 2017/2018 year. Thus, the study met this performance measure. Six of the seven structures had an overall Success Rate over 90 percent by year five of the study. Only the Telegraph Culvert had a low success rate and did not meet this performance measure.

4.4 Fence End Runs

Mule deer movements around fence ends decreased over time. The West Fence End had significant decreases from the first to the second year and stayed low. The East Fence End mule deer end runs did decrease significantly after the first year, but still had approximately 150 mule deer end-of-fence movements detected by the cameras. This may have been in part related to the deterrence of deer at the nearby Buckskin Bridge where a cattle fence was placed on the structure during the 2018 spring migration. Overall though, this performance measure was met.

4.5 Wildlife-Vehicle Collision Crashes

Not only did WVC crashes decrease in the study area, statistical analyses found the decrease in these crashes within the fenced area was significantly different than changes outside the fenced area between Pre-Construction and Post-Construction. This performance measure was met.

4.6 Summary

Overall, all performance measures were met and the wildlife mitigation can be considered a success.

5.0 RECOMMENDATIONS AND IMPLEMENTATION

5.1 Recommendations

Study results support the use of designs for the three wildlife crossing culverts in this project. The heights of 8.5 to 12 feet (2.6 – 3.7 meters), widths of 15.5 to 18.6 feet (4.7- 5.7 meters), and lengths of 52 to 68 feet (15.8-20.7 meters) together for openness ratios of at least 2.53 in feet and 0.77 in meters were large enough for the thousands of mule deer that passed through them over five years. This design of corrugated steel culverts with natural bottoms is recommended.

Previous research on mule deer movements, crash, and carcass data indicated that the area near Telegraph Wash (MP 39.5) was the most important mule deer movement area across US 89 prior to the mitigation. Unfortunately, the existing culvert at Telegraph was not replaced with a suitable wildlife crossing structure for various reasons. While this was unfortunate for the mule deer and other animals who attempted to enter the culvert and repelled away, it proved to create an experiment in convincing mule deer to move their line of migration up and down the fence line. This study documented the adaptation of the Paunsaugunt mule deer herd to the fence and structures. The mule deer Success Movements increased over the study at the New East Culvert at MP 40.5 and the Buckskin MP 37 Bridge, the two structures to either side of the Telegraph Culvert. Mule deer in southern Utah are able to adapt to mitigation measures within one mile of their typical migration patterns.

The mule deer are also documented both in crash data and with Global Positioning System (GPS) collars on deer in a UDWR study (Daniel Olson, UDWR Personal Communication) to be moving west of the mitigation near the Johnson Canyon Road, near MP 53 since at least 2017. Additional efforts will need to be made near this location to build wildlife crossing structures to accommodate the mule deer beneath US 89.

5.2 Implementation Plan

The recommended Implementation Plan includes:

a) A recommendation to convey the results of this study to all UDOT Regions, UDOT Headquarters, to environmental staff, project engineers, planners, and maintenance personnel so they can implement similar mitigation projects;

b) Informing any UDOT staff involved in planning future UDOT projects, managing project development, and maintaining culverts, fences, and bridges in daily operations to evaluate each project for potential wildlife movement needs and manage the resulting mitigation in an adaptive management manner; and

c) Region engineers, project managers, environmental staff and maintenance staff should be informed of the results of this report so they can create and manage wildlife crossing structures, fences, and other features in effective manners.

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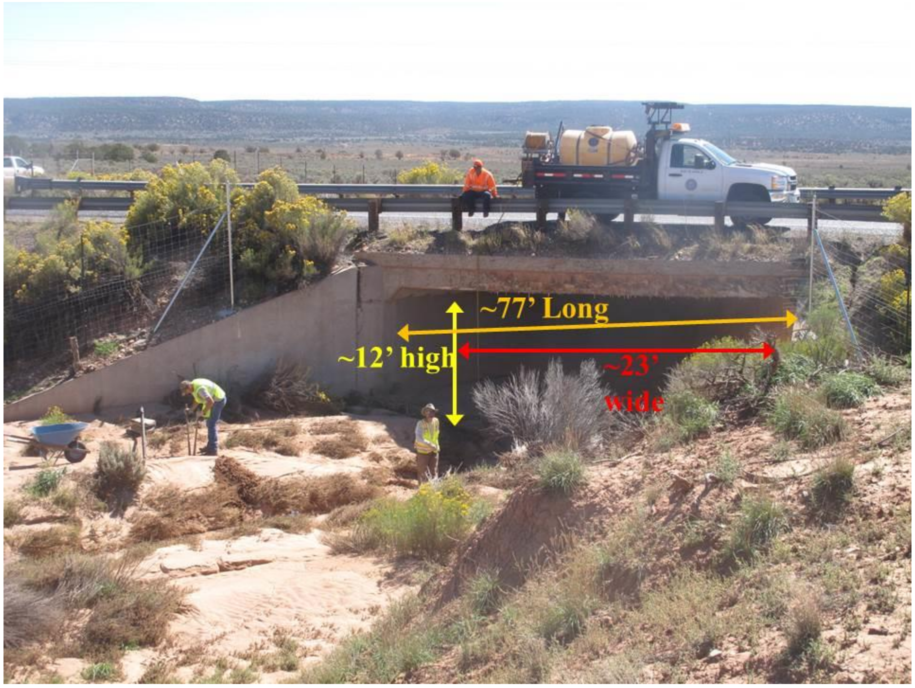
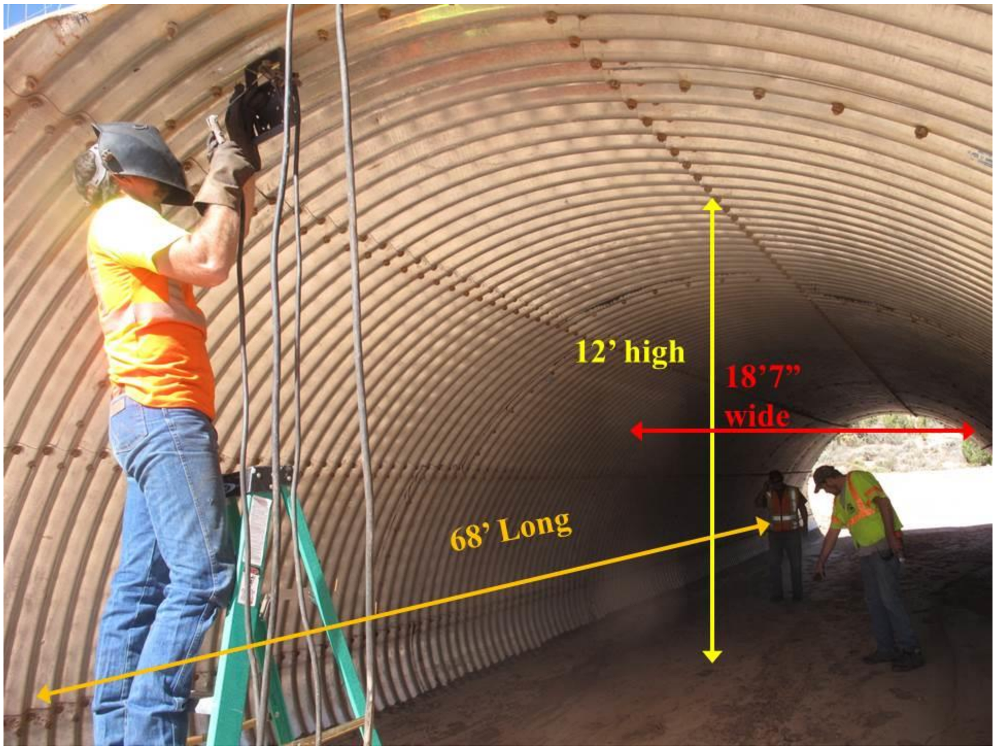
APPENDIX A: STRUCTURES

US 89 MP 48.2 Seaman Wash Existing Concrete Box Culvert.

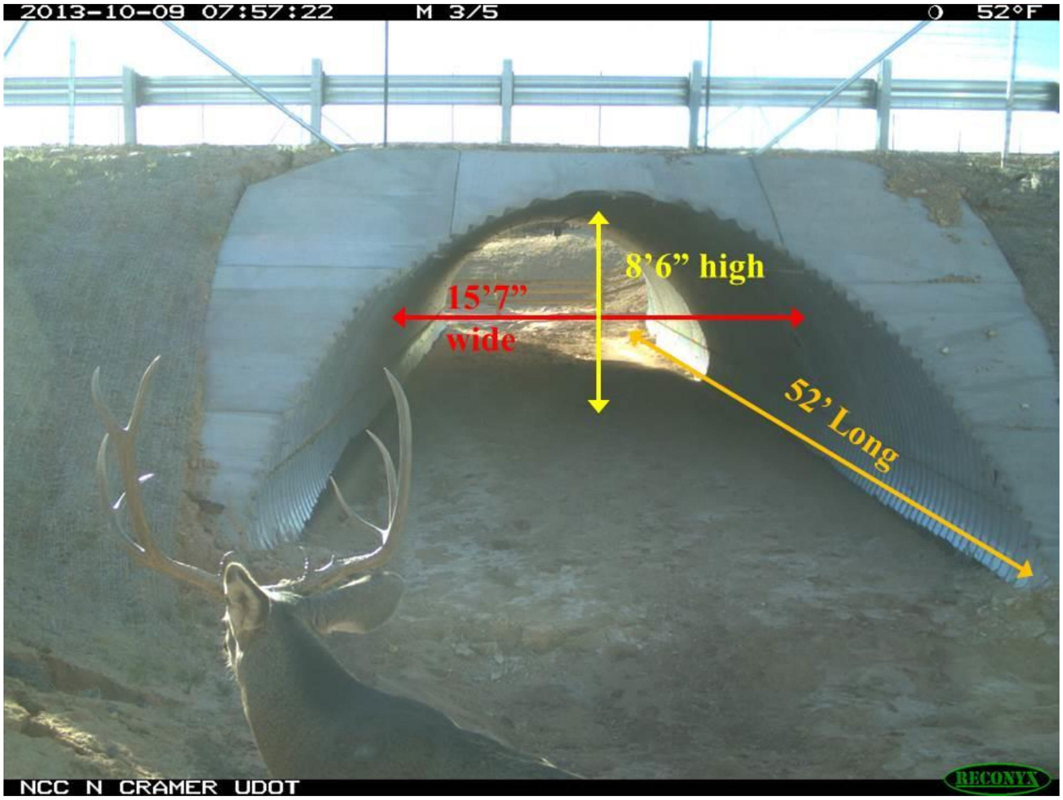


US 89 MP 45.3 Petrified Wash Existing Concrete Box Culvert. AZGF crew sets cameras as UDOT maintenance crew supplies water for concrete.

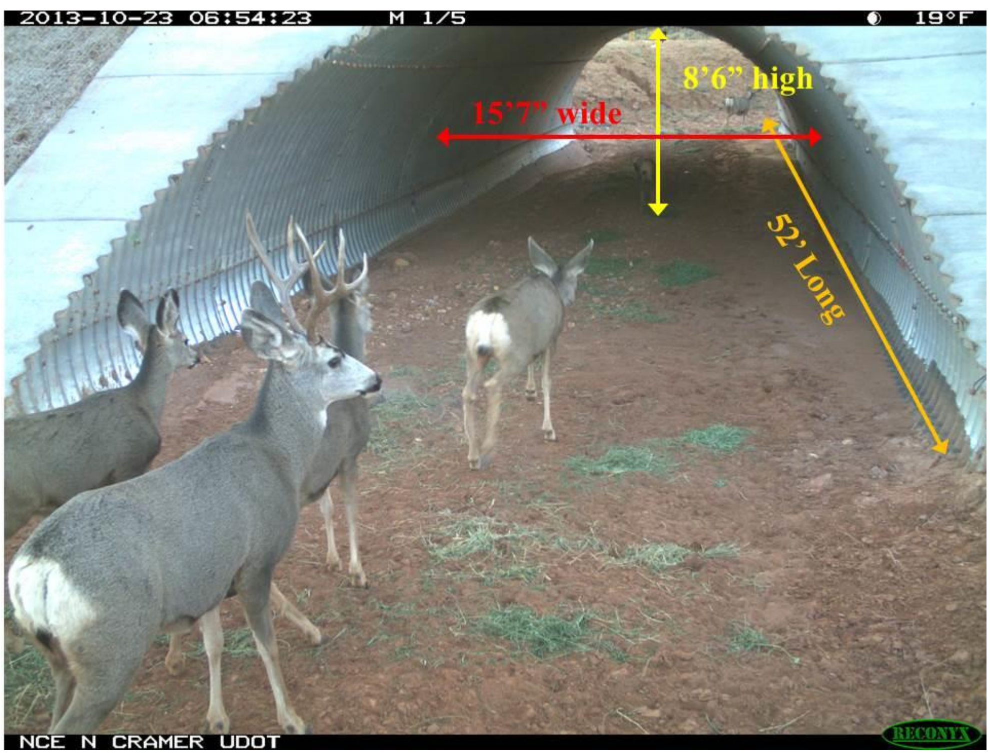


US 89 MP 44 West New Corrugated Steel Culvert Wildlife Crossing. UDOT's Lance Brekerhall welds camera mount to culvert while UDOT's Chet Johnson and AZGF's Jeff Gagnon follow mule

deer tracks through the culvert.

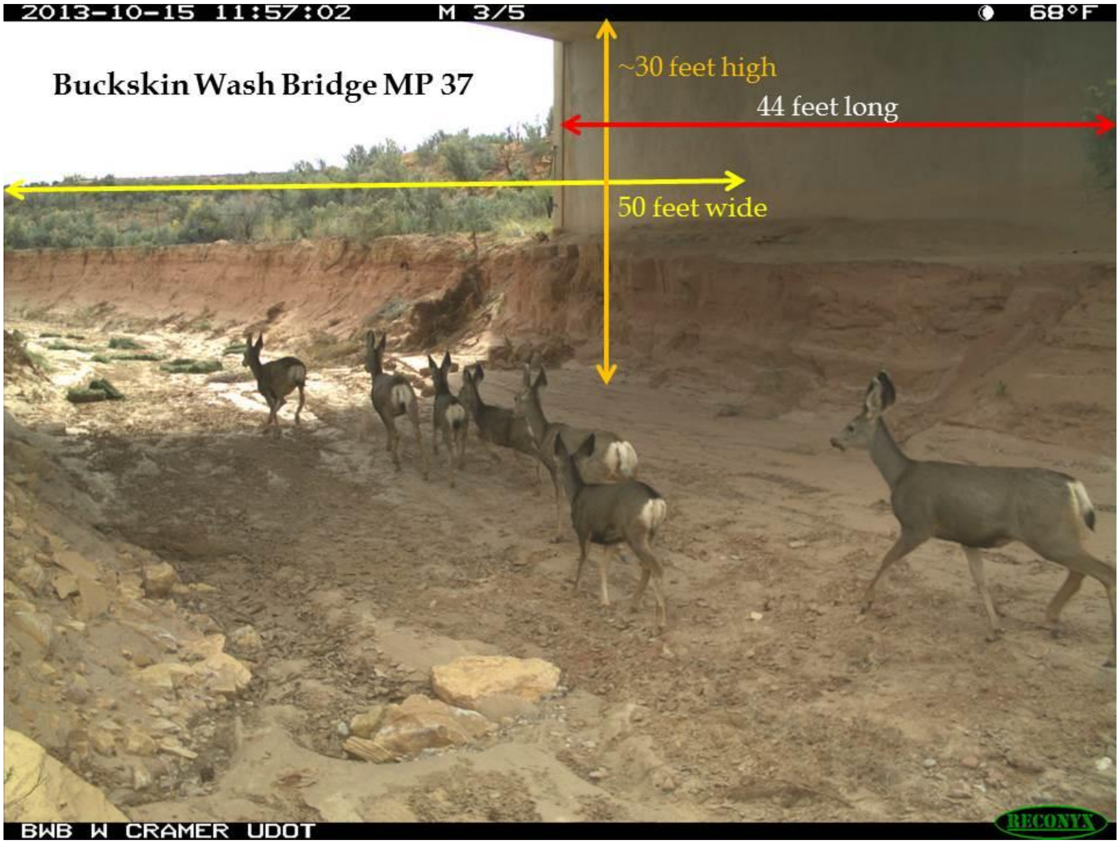


US 89 MP 42.5 Central New Corrugated Steel Culvert Wildlife Crossing.



US 89 MP 40.5 East New Corrugated Steel Culvert Wildlife Crossing.

US 89 MP 39.5 Telegraph Wash Existing Corrugated Steel Culvert.



US 89 MP 37 Buckskin Wash Bridge.

APPENDIX B. PICTURES OF WILDLIFE SPECIES AT STRUCTURES

Select photos are provided to demonstrate the various species of mammals using the structures.

Mule Deer Headed South From Buckskin Bridge, January 2017.

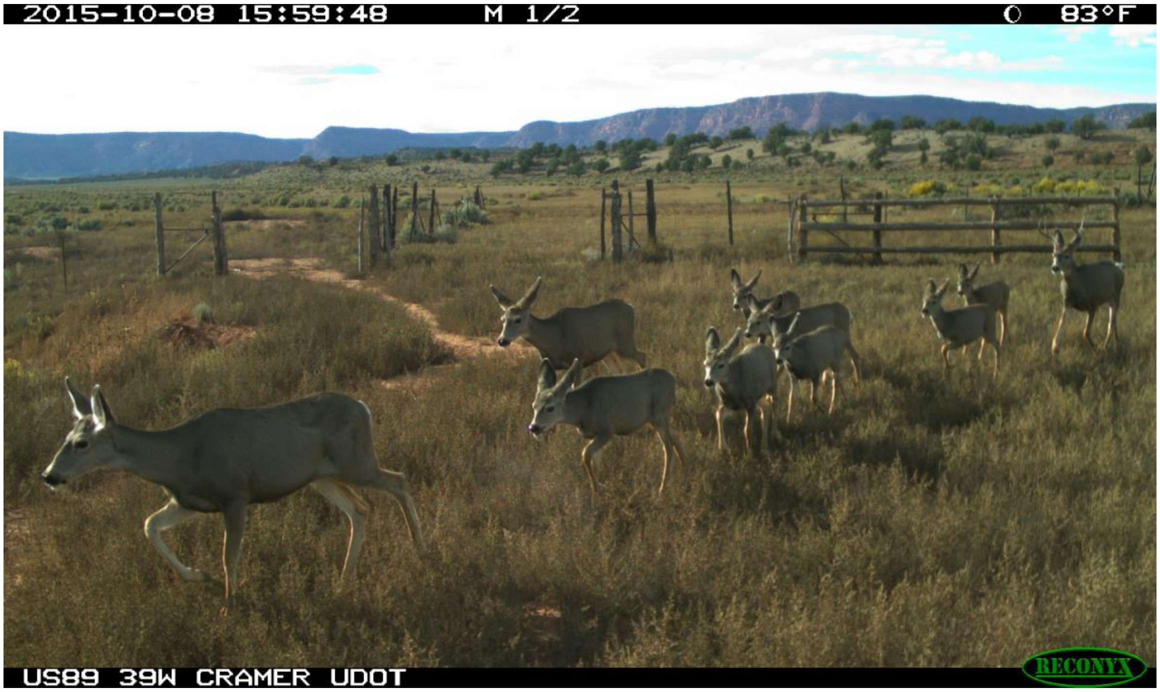
Mule Deer Assessed the Ice at Buckskin Bridge, January 2017.

Mule Deer Moved Through Flash Flood Waters in Buckskin Wash, Buckskin Bridge.

Mule Deer Used the East New Wildlife Crossing in the Second Fall Migration.

Herd of Mule Deer Repelled Away from Telegraph Culvert, First Fall Migration After Construction.

Mule Deer Moved Through the Telegraph Culvert from the South in the 2018 Spring Migration.



Mule Deer Herd Moved from the North Toward Telegraph Culvert in Fall 2015.

Mule Deer Used the Center New Culvert During the First Fall Migration, 2013.

Mule Deer Buck Pondered Using Center New Culvert, October 2013.

Mule Deer Used the Center New Culvert October 2015.

Mule Deer Used West New Culvert, February 2017.

Seaman’s Wash Culvert MP 48 Mule Deer Herd Approached from North.

Mule Deer Approached Then Repelled From Double Cattle Guard at the Summit.

Mule Deer Buck at the West Fence End, North Side, with Eye Shine of Other Mule Deer in Background During the Fall 2013, First Migration South After Construction.

The sole black bear photographed in the study, at MP 44 West New Culvert.

A Young Puma Used Seaman Culvert in 2017.

Petrified Culvert MP 45.5 Elk Cow and Calf Approached Then Repelled from South Side of Culvert.

Cow Elk Successfully Used the Petrified Culvert.

A Bull Elk Went Over the ROW Fence at the East End.

A Mother Puma Took Two Kittens Through the Buckskin Wash Under the Buckskin Bridge.

Pronghorn Antelope Approached and Repelled from Buckskin Bridge.

East New Culvert MP 40.5 Badger Used Culvert from North.

Bobcat Used Center New Culvert MP 42.5 From North.

Bobcat Used Seaman Culvert, February 2017.

Coyote Used West New Culvert MP 44 from North.

Coyote at Petrified Culvert, July 2017.

Coyote Approached and Used Seaman's Culvert, January 2017.

A Road Runner Used the Seaman Culvert.

The Probable Wyoming Wolf That Traveled to the North Rim of the Grand Canyon and Then Headed North Through Utah, Crossing US 89 at Mile Post 43.2 at the Summit of the Study Area.

APPENDIX C. A COMPARISON OF CRASH NUMBERS AND CARCASS NUMBERS BY YEAR, EAST CONTROL, MITIGATION, AND WEST CONTROL SECTIONS

Year	East Control MP 30.00 – 36.1		Mitigation Section MP 36.2- 48.6		West Control MP 48.7 – 56.0	
	Crashes	**Carcasses**	**Crashes**	**Carcasses**	**Crashes**	**Carcasses**
2009	3	3	13	11	4	12
2010	0	0	5	28	5	5
2011	3	0	9	34	10	3
2012	5	0	11	3	5	2
2014	1	1	5	10	15	0
2015	5	1	12	2	10	16
2016	4	1	0	2	19	0
2017	4	0	1	0	10	0
Sub-Totals	25	6	56	90	78	38
Total Crashes	159					
Total Carcasses	134					